

VIRGINIA DEPARTMENT OF AGRICULTURE  
AND IMMIGRATION

**GEOLOGICAL SURVEY OF VIRGINIA**

THOMAS L. WATSON, GEOLOGIST IN CHARGE

---

GEOLOGICAL SERIES, BULLETIN NO. II.

---

**The Clay Deposits of the Virginia Coastal Plain**

BY

HEINRICH RIES

WITH A CHAPTER ON

**The Geology of the Virginia Coastal Plain**

BY

WILLIAM BULLOCK CLARK

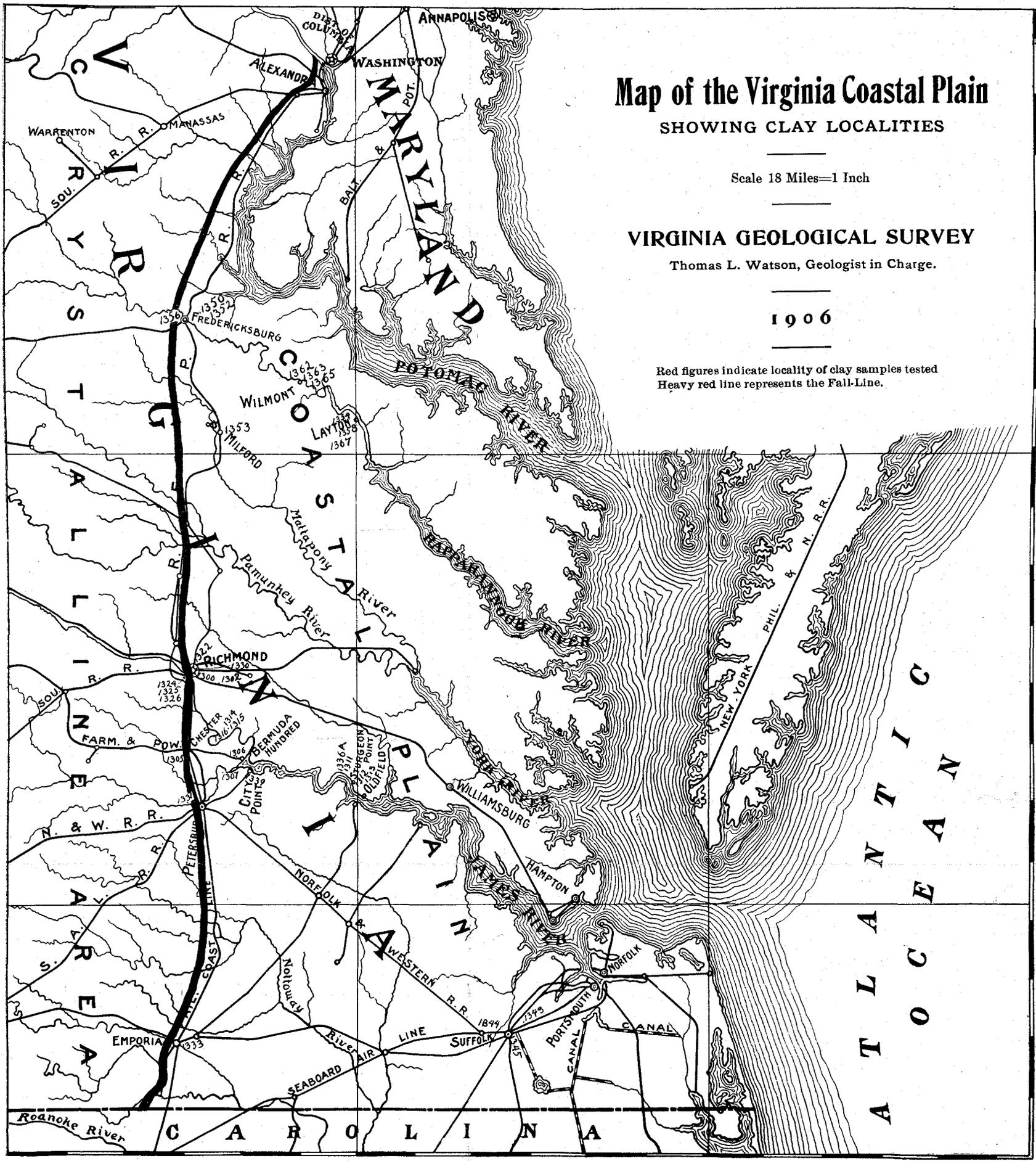
*and*

BENJAMIN LEROY MILLER

---

PUBLISHED BY  
BOARD OF AGRICULTURE AND IMMIGRATION  
1906

LYNCHBURG, VA. :  
J. P. BELL COMPANY, PRINTERS AND BINDERS.  
1906.



# Map of the Virginia Coastal Plain

## SHOWING CLAY LOCALITIES

Scale 18 Miles=1 Inch

**VIRGINIA GEOLOGICAL SURVEY**

Thomas L. Watson, Geologist in Charge.

1906

Red figures indicate locality of clay samples tested  
 Heavy red line represents the Fall-Line.



## PREFACE

---

The present volume forms Bulletin No. II of the series of reports issued on the economic geology of Virginia, under the co-operation of the State Board of Agriculture and the Board of Visitors of the Virginia Polytechnic Institute.

This report is based on field work carried on during the summer of 1905. The investigation was limited to the clays of the Coastal Plain Area or the Tidewater Belt of Virginia. Beginning with the next field season, it is expected that this work will be extended as rapidly as possible to all portions of the State and, when completed, a final volume will be issued on the clays and clay industry of the entire State.

The investigation of the Virginia clays was undertaken for the purpose of determining (1) the extent, qualities, and applicability of the clays; and (2) whether the clays now being utilized could be used for making other or better products than are now being made from them. This is fully covered for the Coastal Plain clays in the summary given by Dr. Ries under *Clay Working Industry of the Virginia Coastal Plain and Its Future Tendency*, on pages 175 and 176 of this report, to which the reader is especially referred. In the prosecution of the field work a large number of samples of the clays were collected from the various deposits and submitted to careful chemical and physical investigation, the results of which are given in Part II, Chapter V of this report.

*The Geology of the Virginia Coastal Plain*, by Dr. Wm. Bullock Clark and Dr. Benjamin LeRoy Miller, forms Part I of the report. It is a brief summary of our present knowledge of the Virginia Coastal Plain stratigraphy, and was prepared to be used as a basis or guide in the correlation of the various clay deposits described by Dr. Ries in Part II, Chapter V. A report, treating in considerable detail of the Virginia Coastal Plain stratigraphy, prepared under the direction of Dr. Clark, is nearly completed and will be published as a separate report by the Virginia Survey.

## THE BOARDS OF CONTROL OF THE SURVEY

---

### VIRGINIA STATE BOARD OF AGRICULTURE AND IMMIGRATION

C. W. HEATER, President.....	Middletown
J. H. C. BEVERLEY.....	Chance
A. O. MAUCK.....	Yorktown
JULIAN M. RUFFIN.....	Old Church
J. THOMAS GOODE.....	Skipwith
J. M. BARKER.....	Axton
J. T. COWAN.....	Cowan's Mills
WM. H. EGGBORN.....	Eggbornville
JAMES R. GOODWIN.....	Eggleston
W. B. LEECH.....	Oakdale
J. M. McBRYDE, Member ex-officio.....	Blacksburg

---

### BOARD OF VISITORS, VIRGINIA POLYTECHNIC INSTITUTE

J. THOMPSON BROWN, Rector.....	Brierfield
J. C. CARRINGTON.....	Charlotte
W. B. ROBERTSON.....	Plasterco
J. B. WATKINS.....	Hallsboro
B. B. BROCKENBROUGH.....	Tappahannock
D. M. CLOYD.....	Dublin
J. S. MUSGRAVE.....	Pinopolis
J. F. RYAN.....	Areola
J. D. EGGLESTON, JR., Superintendent Public Instruction, Mem- ber ex-officio.....	Richmond
C. W. HEATER, President Board of Agriculture, Member ex-officio .....	Middletown

## TABLE OF CONTENTS

	PAGE
Preface.....	11
Part I. The Geology of the Virginia Coastal Plain.....	24
Chapter I. The Geology of the Virginia Coastal Plain.....	12-14
Introduction.....	14-24
The Formations.....	14-15
The Jurassic (?) Period.....	14
Upper Jurassic.....	14-15
The Patuxent Formation.....	15
The Arundel Formation.....	16
The Cretaceous Period.....	16
Lower Cretaceous.....	16
The Patapsco Formation.....	16
The Tertiary Period.....	16
Eocene.....	16-17
The Aquia Formation.....	17
The Nanjemoy Formation.....	18
Miocene.....	18
The Calvert Formation.....	18-19
The Choptank Formation.....	19
The St. Mary's Formation.....	19-20
The Yorktown Formation.....	20
Pliocene.....	20
The Norfolk Formation.....	20-21
The Lafayette Formation.....	21
The Quaternary Period.....	21
Pleistocene.....	21-22
The Sunderland Formation.....	22-23
The Wicomico Formation.....	23
The Talbot Formation.....	24
Recent.....	25
Part II. The Clay Deposits of the Virginia Coastal Plain.....	27-91
Chapter II. The Origin, Properties, and Mode of Occurrence of Clay...	27
Introductory.....	27-30
Clay defined.....	28-36
Origin of Clay.....	30-32
Residual Clay.....	32
Uses of Residual Clays.....	32-34
Sedimentary Clays.....	34-36
Classification of Sedimentary Clays.....	34-35
Marine Clays.....	35
Estuarine Clays.....	35
Swamp and Lake Clays.....	35-36
Flood-Plain and Terrace Clays.....	36
Drift or Boulder Clays.....	36-45
Secondary Changes in Clay Deposits.....	37-41
Mechanical Changes.....	37-38
Folding, Tilting, and Faulting.....	38-41
Erosion.....	41-45
Chemical Changes.....	41-43
Change of Color.....	43
Leaching.....	43-44
Softening.....	44
Consolidation.....	44-45
Formation of Shale.....	45-47, 88-91
Chemical Properties of Clay.....	45-47
The Combination of Elements in Clay.....	45-47

TABLE OF CONTENTS

	PAGE
Minerals in Clay.....	47-52
Quartz.....	47
Feldspar.....	47-48
Mica.....	48
Iron Ores.....	48-49
Pyrite.....	49
Glauconite.....	49-50
Kaolinite.....	50
Rutile.....	50-51
Calcite.....	51
Gypsum.....	51
Hornblende and Garnet.....	51-52
Dolomite.....	52
The Chemical Analysis of Clays.....	52-55
Ultimate Analysis.....	52-54
Rational Analysis.....	54-55
Mineral Compounds in Clay and their Chemical Effects.....	55-71
Silica.....	55-57
Iron Oxide.....	57-58
Effects of Iron Compounds.....	58-60
Coloring Action of Iron in Unburned Clays.....	58
Coloring Action of Iron in Burned Clays.....	58-60
Effect on Absorptive Power and Shrinkage of Clay.....	60
Lime.....	60-63
Effect of Lime Carbonate on Clay.....	61-62
Effect of Lime-Bearing Silicates.....	62
Effect of Gypsum.....	63
Magnesia.....	63-64
Alkalies.....	64-66
Titanium.....	66
Water.....	67-68
Mechanically Admixed Water.....	67-68
Chemically Combined Water.....	68
Carbonaceous Matter.....	68-71
Black Coring in Virginia Clays.....	70-71
Effect of Water on Black Coring.....	71
Physical Properties of Clay.....	71-85
Plasticity.....	71
Tensile Strength.....	71-72
Shrinkage.....	72
Air Shrinkage.....	73
Fire Shrinkage.....	73-75
Fusibility.....	75-84
Temperature of Fusion.....	77-78
Classification of Clays Based on Fusibility.....	78
Determination of Fusibility.....	78
Seger Cones.....	79-83
Thermo-Electric Pyrometer.....	83-84
Texture.....	84
Color.....	84-85
Slaking.....	85
Specific Gravity.....	85
Chemical and Physical Properties of the Coastal Plain Clays in Virginia.....	86-91

TABLE OF CONTENTS

	PAGE
Physical Properties.....	86-88
Chemical Properties .....	88-91
Chapter III. Exploiting and Mining Clays.....	91-97
Prospecting for Clays.....	91
Outcrops.....	91
Springs.....	91-92
Exploitation.....	92
Winning the Clay.....	92-93
Methods of Mining.....	93
Underground Workings .....	93-94
Surface Workings.....	94-96
Pit-Mining for Kaolin .....	96
Preparation of Clay after Mining .....	96-97
Washing.....	96-97
Details.....	96-97
Chapter IV. The Manufacture of Clay Products .....	98-131
Introduction.....	98
Uses of Clay.....	98-99
Domestic.....	98
Structural.....	98
Hygienic.....	98
Decorative .....	98
Minor Uses .....	98
Refractory Wares .....	98-99
Engineering Works.....	99
Classification of Clays.....	99-100
Kaolin.....	99
Ball Clays.....	99
Fire Clay .....	99
Stone Ware Clays.....	99
Sagger Clay .....	99
Terra Cotta Clay.....	99
Retort Clay.....	100
Pipe Clay .....	100
Brick Clay.....	100
Paper Clay.....	100
Paving Brick Clay .....	100
The Methods of Manufacture.....	100-103
The Manufacture of Building Brick.....	100
Raw Materials .....	101-103
Clays for Common Brick.....	101-102
Pressed Brick.....	102-103
Methods of Manufacture.....	100-103
Preparation .....	103
Weathering.....	103
Dry Crushing .....	103
Crushers.....	104
Rolls .....	104
Disintegrators.....	105
Dry Pans.....	105
Ball Mills.....	105
Machine for Preparing Wet Clay.....	106
Soak Pits and Ring Pits .....	106
Pugmills.....	106
Wet Pans.....	106
Screens .....	107
Molding .....	107
Soft-Mud Process.....	107-108
Stiff-Mud Process.....	109-111

TABLE OF CONTENTS

	PAGE
Repressing .....	111-112
Dry-Press Process.....	112-114
Drying.....	114-117
Burning.....	117-126
General Effects.....	118-119
Effects Due to Variation in the Clay.....	119-120
Flashing .....	120-122
Kilns .....	122-126
Up-draft Kilns .....	122-123
Down-draft.....	123-126
Continuous Kilns.....	126
Paving Brick.....	126-127
Drain Tile.....	127
Hollow Ware for Structural Work.....	128-129
Fire Proofing.....	128
Terra Cotta Lumber.....	128
Hollow Blocks.....	128
Hollow Brick.....	128
Lightness.....	129
Pottery Manufacture.....	129-131
Raw Materials.....	129-130
Manufacture.....	130-131
Chapter V. Detailed Account of the Virginia Coastal Plain Localities	131-176
Alexandria County.....	132-134
The Alexandria Area and Vicinity.....	132-134
Spottsylvania County.....	134-137
The Fredericksburg Area .....	134-137
King George County.....	137-139
The Wilmont Area .....	137-139
Essex County.....	140-141
The Layton Area.....	140-141
The Diatomaceous Earth Deposits .....	143-144
Uses of Diatomaceous Earth.....	143-144
Caroline County.....	144-145
The Milford Area.....	144-145
Henrico County.....	145-151
The Richmond Area.....	145-157
The Fort Lee Area.....	151-156
Summary.....	153-154
The Curle's Neck Area.....	154-156
Chesterfield County.....	157-159
The Chester Area.....	157-158
The Bermuda Hundred Area.....	158-159
Dinwiddie County.....	159-161
The Petersburg Area.....	159-161
Prince George County.....	161-164
The Broadway Area.....	161-163
The City Point Area.....	163-164
Charles City County.....	164-169
The Sturgeon Point Area.....	164-166
The Oldfield Area.....	166-169
Greensville County.....	169-170
The Belfield Area.....	169-170
Norfolk County .....	170-171
The Norfolk Area and Vicinity.....	170-171
Nansemond County.....	172-175
The Suffolk Area .....	172-175
The Clay Working Industry of Virginia Coastal Plain Area and its future Tendency.....	175-176

## ILLUSTRATIONS.

PLATE	Facing Page
I. Map of the Virginia Coastal Plain showing localities of clay samples tested.....	1
II. A. Cross-bedded clay, sand and gravel. Harbaugh's pit, Richmond.....	50
B. Deposit of loamy clay overlain by gravel, showing sudden change of character often met with in sedimentary clay and sand deposits. Brower's pit, Richmond.....	50
III. Ring pit used for tempering clay.....	105
IV. Soft-mud brick machine.....	107
V. A stiff-mud brick machine; shows bar of clay issuing from die.....	109
VI. Cutting table of stiff-mud brick machine; shows revolving cutter, and the cut brick coming from cutting table.....	118
VII. Stiff-mud brick machine and revolving cut-off, for making side-cut brick.....	124
VIII. A. Car of green brick.....	129
B. Up-draft kiln, with permanent side-walls but no roof.....	129
IX. View of Washington Hydraulic-Press Brick Company's Works.....	134
X. A. General view of Redford's clay bank and brick yard.....	146
B. View of clay pit at Manchester, showing boulders in the clay.....	146
XI. A. General view of Keeler's brick yard at Broadway on the Appomattox river.....	161
B. Keeler's clay bank at Broadway on the Appomattox.....	161
XII. A. General view of Oldfield Brick Co.'s yard, Oldfield on James River.....	166
B. Clay pit of Oldfield Brick Co.....	166
XIII. A. Ferruginous sandy clay; a type not uncommon around Petersburg.....	168
B. General view of Turner's clay pit, Ettricks, near Petersburg.....	168
XIV. A. Clay bank of Standard Brick Co., near Suffolk.....	172
B. Bluffs of diatomaceous earth (Miocene age) along Rappahannock river southwest of Wilmont.....	172
XV. A. Diatomaceous earth overlain by Pleistocene clay at Wilmont.....	175
B. General view of brick plant at Wilmont.....	175
FIGURE	Page
1. Section showing passage from residual clay on surface to parent rock below.....	30
2. Section showing how sedimentary clay beds may vary, etc.....	33
3. Section showing clay bed (a), with uneven surface caused by erosion.....	37
4. Section in horizontally stratified beds of clay and sand.....	38
5. East-west section, showing out-cropping beds of inclined strata.....	39
6. Section of vertical beds.....	39
7. Section of folded beds.....	40
8. Section of beds folded into a syncline.....	40
9. Inclined beds, showing how they are found at continually higher levels if followed up their slope or dip.....	41
10. Section illustrating how weathering penetrates a clay along joint-planes, etc.....	42

## LETTER OF TRANSMITTAL

---

*To the Members of the Virginia Board of Agriculture and Immigration, and the Board of Visitors of the Virginia Polytechnic Institute:*

Gentlemen—I have the honor to submit herewith a report on the Clay Deposits of the Virginia Coastal Plain, by Dr. Heinrich Ries, Assistant Professor of Economic Geology in Cornell University; and to request that it be published as Volume II of the Geological Series of the Virginia Survey.

Respectfully,

THOMAS L. WATSON,

Blacksburg, Va., March 15th, 1906.      Geologist in Charge.

In Part II, Chapters, II, III, and IV, Dr. Ries discusses in considerable detail the origin, mode of occurrence, physical and chemical properties of clay; the methods of exploiting, mining, and preparation of clay; and the methods of manufacture of the different clay products, with particular reference to the Virginia Coastal Plain clays. A detailed description of the Coastal Plain clays is given in Chapter V, including their chemical and physical properties and uses, summarized by counties.

The large number of complete chemical analyses of the clays described in the report were made by Mr. John R. Eoff, Jr., and Mr. James H. Gibboney, assisted by Mr. D. D. Spiller, in the laboratories of the Virginia Polytechnic Institute, at Blacksburg. The physical tests made of the same clays, including air shrinkage, fire shrinkage, color in burning, temperature of vitrification, and of fusion, etc., were carried out under the immediate direction of Dr. Ries in his laboratory at Cornell University, Ithaca, N. Y. Mr. Henry F. Day, a student in geology at the Virginia Polytechnic Institute, served as field assistant to Dr. Ries during the season's work.

THOMAS L. WATSON,  
Geologist in Charge.

Part I

---

A BRIEF SUMMARY OF

The Geology

of the

Virginia Coastal Plain

---

By WILLIAM BULLOCK CLARK

and BENJAMIN LE ROY MILLER

## CHAPTER I.

### THE GEOLOGY OF THE VIRGINIA COASTAL PLAIN.

---

#### INTRODUCTION.

The Virginia Coastal Plain is an area of low relief that slopes gradually from the Piedmont hill country to the ocean border, beyond which it is represented in the shallow sea floor that declines gently to the margin of the continental shelf. The submarine division is not materially different from the subaerial division and has often stood above the sea level, the coast line having shifted its position in successive geological periods all the way from the Piedmont border far out toward the edge of the continental shelf where the ocean bed falls rapidly to the greatest depths.

The great body of deposits forming the Coastal Plain has been laid down along the border of the Piedmont on the floor of crystalline rocks of which that district is composed. At first estuarine in character, these sediments were later of marine origin and continued to be chiefly such until the later geological epochs, when the surficial deposits of the Pleistocene were laid down in the enclosed bays and estuaries of the dissected Coastal Plain district. As the sea stood at different elevations throughout this partially eroded area, a series of terraces were developed similar in character to that now forming along the margin of the tidal bays and streams that penetrate the Coastal Plain in all directions and give to the country the name of "tide-water" Virginia. Farther up the streams flood-plain deposits were laid down, most of which have disappeared as the result of erosion in the subsequent elevations of the area.

Across the district stretches the great estuary of the Chesapeake Bay, which finds its outlet seaward between Capes Charles and Henry. This sheet of water, so broad and deep today, affords the great highway of commerce for Virginia's export trade as well as the unparalleled local transportation facilities for the tide-water country. It occupies the lower valley of the old Susquehanna River which flowed across Maryland and Virginia and

found its way seaward, past the Capes, its channel being traced today across the sea floor of the submarine portion of the Coastal Plain. Its many tributaries, among them the Potomac, Rappahannock, York, and James Rivers, give access to vessels as far as the Piedmont border, widely known in geological literature as the "fall-line," since at this point the swiftly flowing streams of the Piedmont change rapidly, their strong currents becoming lost in the tidal estuaries.

Although composed of a succession of formations which represent nearly every period from the Jurassic to the Recent, the Coastal Plain deposits do not succeed each other in a conformable series, nor do they possess the same strikes and dips. A differential movement, at times pronounced and materially influencing the attitude of the beds, has so affected the district that transgressions have occurred, eliminating in certain sections the landward exposures of whole formations that appear in adjacent regions. Thus the upper Cretaceous deposits, so well exhibited in Maryland, are gradually transgressed by the Eocene southward, shutting out the former throughout the entire area of outcrop in Virginia although recognized in the deep-well borings at Fortress Monroe.

The deposits of the Coastal Plain for the most part consist of unconsolidated beds of sand, gravel, clay, and marl which may be locally indurated by the presence of a cement either of iron oxide or carbonate of lime. At times these indurated ledges serve as sources of building stone for local uses, and in one instance, viz., near Aquia Creek, the oldest formation of the Coastal Plain series has afforded stone suitable for export, this material having been employed for building purposes in Washington before the days of railroad transportation.

In general the beds strike from north to south, although some variation occurs as above explained. The strata have a general easterly dip which changes from 30 feet to the mile in the lowest formations—about the slope of the crystalline floor on which the deposits rest—to less than five feet to the mile in the highest deposits. With this relatively low dip the beds generally appear horizontal in any given section and may be actually so locally, so that measurements must be extended over a wide area before the average dip of any particular formation can be determined.

Along the eastern margin of the Piedmont district outliers of the Coastal Plain formations are frequent, while along the valleys of the larger streams the crystallines can at times be followed for some distance into the body of the Coastal Plain sediments where the mantle of the latter has been cut through.

#### THE FORMATIONS.

The formations comprising the Virginia Coastal Plain are given in the following table:

#### FORMATIONS OF VIRGINIA COASTAL PLAIN.

##### CENOZOIC

##### Quaternary

Recent

Pleistocene..... { Talbot  
Wicomico } Columbia Group  
Sunderland }

##### Tertiary

Pliocene..... { Lafayette  
Norfolk }

Miocene..... { Yorktown  
St. Mary's } Chesapeake Group  
Choptank  
Calvert }

Eocene..... { Nanjemoy } Pamunkey Group  
Aquia }

##### MESOZOIC

##### Cretaceous

Lower Cretaceous..... Patapsco } Potomac Group

##### Jurassic?

Upper Jurassic?..... { Arundel  
Patuxent }

#### THE JURASSIC (?) PERIOD.

##### UPPER JURASSIC?

##### *The Patuxent Formation.*

The Patuxent formation, so called from Patuxent River, Maryland, where the deposits are well exposed, constitutes the basal portion of what was originally described as the Potomac formation but which is now known to comprise several distinct stratigraphic units. The Patuxent formation has only been recognized

in the Chesapeake Bay drainage basin in Virginia and Maryland although it may exist farther southward. To the northward in New Jersey it has been overlapped by later deposits. In Virginia the formation is found near the head of tide in the leading drainage basins directly overlying the floor of crystalline rocks.

The deposits consist chiefly of sand, sometimes quite fine and gritty, but generally containing a considerable amount of kaolinized feldspar producing a clearly defined arkose. Sandy and plastic clays also occur, the latter commonly of light color, but often highly colored and locally not unlike the variegated clays of the Patapsco formation. The Patuxent formation includes the James River series and part of the Rappahannock series of Ward, and has a thickness of 250 to 300 feet. The fossils consist of plant remains, among which the cycàds are the most distinctive. A few primitive dicotyledons also occur.

---

#### *The Arundel Formation.*

The Arundel formation, so named from Anne Arundel County, Maryland, is but poorly shown in Virginia, its maximum development occurring in Maryland. Certain clays in the vicinity of Mt. Vernon are thought to represent this formation. Further study of the Virginia region may result in the discovery of additional beds of this age.

The deposits consist of dark clays generally highly lignitic and in Maryland often carry large quantities of nodules of iron carbonate. The beds are thought to represent swamp accumulations in warped valleys of post-Patuxent time. The fossils are highly significant, since they consist in part of dinosaurian remains that are regarded by many vertebrate paleontologists as affording proof of the Jurassic age of the deposits, although the paleobotanists regard the beds as Lower Cretaceous. The plant remains are, however, not distinctive and the flora could with almost equal propriety be classed as Jurassic. For the present, therefore, the Arundel formation, together with the Patuxent which underlies it, is questionably referred to the Jurassic and assigned to its upper division.

THE CRETACEOUS PERIOD.  
LOWER CRETACEOUS.

---

*The Patapsco Formation.*

The Patapsco formation, so called from the Patapsco River in Maryland, overlies the Patuxent and Arundel formations unconformably. It has been traced in a broad belt across Maryland and Virginia and is found in isolated remnants to the northward in Delaware and Pennsylvania. Its southward extension has not been studied.

The deposits consist largely of highly-colored and variegated clays that grade over into lighter-colored sandy clays, while sandy bands of coarser character are at times interstratified. The sandy beds are sometimes arkosic and often carry clay lumps. The formation has a thickness of about 150 feet and dips about 30 feet in the mile to the eastward. The fossils are chiefly plants, among which many dicotyledons are found, and the formation is unquestionably Lower Cretaceous in age.

The Patuxent, Arundel, and Patapsco formations, together with the Raritan formation of Maryland, Delaware, and New Jersey, constitute the Potomac group.

The Raritan, Magothy, Matawan, Monmouth, and Rancocas, formations, the last three representing the greensand series of New Jersey south of Delaware Bay in Delaware and Maryland, are gradually transgressed one after the other by the Eocene deposits to the southward, and have not been found along the line of outcrop south of the Potomac River in Virginia. The Cretaceous greensands have been penetrated in the deep wells at Fortress Monroe so that some at least of these absent formations are buried beneath the later deposits farther to the eastward in the Virginia Coastal Plain.

---

THE TERTIARY PERIOD.

EOCENE.

---

*The Aquia Formation.*

The Aquia formation, so called from Aquia Creek in Stafford County where the most conspicuous section of the deposits of this

horizon occur, first appears beneath the northward transgressing Miocene deposits near the Delaware-Maryland line from which point it extends across Maryland into Virginia where it rests unconformably on the Patapsco formation.

The deposits consist of greensands and greensand marls, the latter often holding great quantities of molluscan shells that afford at times a cement which causes the beds to be indurated into hard limestone ledges. Beds of clay occur but are less conspicuous than in the overlying Nanjemoy. The formation has a thickness of about 100 feet in the Potomac River region where it dips to the eastward at somewhat less than 15 feet to the mile. The fossils are numerous and distinctive, most of the important groups of animal life being represented, the marine mollusca predominating. The deposits are of undoubted Eocene age.

---

#### *The Nanjemoy Formation.*

The Nanjemoy formation, so called from Nanjemoy Creek, in Maryland, is first recognized on the western shore of Maryland in Anne Arundel County, from which point it stretches across the state into Virginia and has been recognized as far south as the James River basin. The deposits rest conformably on those of the Aquia throughout the area.

The Nanjemoy, like the Aquia formation, consists largely of greensands but at the same time contains a larger element of argillaceous materials, the basal bed known as the Marlboro clay extending from central Maryland across the Potomac into Virginia. This clay bed consisting of 25 feet of compact clay, the lower part pink in color, the upper white, is well developed between Potomac Creek and the Rappahannock River. The Nanjemoy formation has a thickness of about 125 feet and has a dip of from 12 to 15 feet in the mile to the eastward. The fossils are numerous and distinctive and consists, as in the Aquia formation, largely of marine mollusca of characteristic Eocene types.

The Aquia and Nanjemoy formations together constitute the Pamunkey group which is now recognized to consist of two clearly defined formations which can be readily traced across the region.

## MIOCENE.

*The Calvert Formation.*

The Calvert formation, so called from Calvert County, Maryland, in which region the deposits of this horizon are well exposed, along the high cliffs of the Chesapeake Bay, is first recognized in southern New Jersey, from which point it extends across Delaware and Maryland into Virginia. To the north of Maryland the Calvert formation rests directly on the Upper Cretaceous deposits by the overlapping of the Eocene northward, but south of the Delaware-Maryland line it overlies first the Aquia and then the Nanjemoy formation from central Maryland southward into Virginia.

The deposits consist chiefly of clays, sands, and diatomaceous earth. The clays are commonly sandy and at times highly calcareous but the latter less frequently appear as indurated ledges than in the Eocene. The diatomaceous earth is especially well developed in the lower part of the formation, although occurring in greater or less amounts in the upper beds and at higher horizons in the Miocene. Diatomaceous earth consists of the remains of vast numbers of diatoms which are microscopic plant forms with siliceous tests. This material which has been worked at many points is known in the trade as "infusorial earth," "tripoli," or "silica." It has also been called "Richmond earth" and "Bermuda earth," from localities in Virginia. The Calvert formation has a thickness of 150 to 200 feet and a dip of about 10 feet in the mile to the eastward. The fossils of the Calvert formation consist of the remains of marine organisms, chiefly mollusca, which are characteristically Miocene.

*The Choptank Formation.*

The Choptank formation, which receives its name from the Choptank River in Maryland, overlies the Calvert formation unconformably and gradually transgresses the latter northward, and in New Jersey rests directly on the Upper Cretaceous deposits. This formation is prominently exposed in southern Maryland and Virginia, outcropping in a nearly complete section in the Nomini Bluffs on the Potomac River.

The deposits consist of clays, sands, and diatomaceous earth, the sands being more largely developed than in the underlying Calvert formation. The clays are sandy and frequently calcareous. The diatomaceous earth is more prominent at this horizon than in the same formation in Maryland. The formation has a thickness of about 125 feet and the beds dip to the eastward at about 10 feet in the mile. The fossils are largely marine mollusca and although many of the same species occur in the Calvert formation, other and characteristic forms are found.

---

#### *The St. Mary's Formation.*

The St. Mary's formation, so called from St. Mary's County and river, Maryland, is buried beneath the Pleistocene cover in New Jersey, Delaware, and the Eastern Shore of Maryland, but outcrops in the bluffs of the Chesapeake Bay and its tributaries in lower southern Maryland and across the central district of the Virginia Coastal Plain. The formation overlies the Choptank formation conformably.

The deposits consist primarily of clays and sands, the former often blue in color and rich in calcareous matter from the disintegrated molluscan shells that often fill the beds. This shell marl has been employed for agricultural purposes. The formation is about 150 feet thick and has a dip of about 10 feet in the mile to the eastward. The fossils are chiefly marine mollusca as in the other Miocene formations although many representatives of other classes of animal life are found.

---

#### *The Yorktown Formation.*

The Yorktown formation, which receives its name from Yorktown, Virginia, apparently overlies the St. Mary's formation conformably. The infrequent exposure of the beds, due to the heavy cover of later sediments, renders it difficult to determine many of its characteristics and its entire area of outcrop. It does not appear at the surface in Maryland, although, perhaps, part of the great thickness of Miocene beds penetrated in the Crisfield well should be assigned to this formation.

The deposits which consist of sands and clays are crowded with remains of calcareous shells, chiefly marine mollusca, and at Yorktown and on the James River afford the most highly fossiliferous beds in the Chesapeake Bay region. Thick beds almost entirely composed of broken shells, representing shallow-water deposition, form the most striking feature. The thickness of the formation is apparently in excess of 100 feet. The fossils show certain differences when compared with the underlying Miocene formations, and evidently represent a distinct faunal aggregate.

The Calvert, Choptank, St. Mary's and Yorktown formations combined constitute the Chesapeake group. The deposits have many common characters, both physical and faunal.

---

#### PLIOCENE.

##### *The Norfolk Formation.*

The Norfolk formation, so called from Norfolk County, Virginia, where the deposits have been recognized in the deep cutting in the Dismal Swamp Canal, probably forms the northward extension of the Pliocene beds of North Carolina where the strata of this age are much more extensively developed than in Virginia. The deposits are buried beneath a heavy mantle of later Pleistocene sediments so that the areal extent and thickness cannot be readily determined. To the northward, in southeastern Maryland, if the deposits occur they must be deeply buried beneath the Pleistocene.

The deposits consist of clays and sands, the physical characteristics of the material being not unlike the Miocene strata beneath. In places the sandy clays, as in the canal cuts below Portsmouth, contain great quantities of shell remains, making the beds distinctly calcareous. The formation probably does not reach a thickness of 50 feet in Virginia. The fossils are chiefly marine mollusca of characteristic Pliocene types.

---

##### *The Lafayette Formation.*

The Lafayette formation, so named from Lafayette County, Mississippi, has been traced as a nearly continuous mantle over the older members of the Coastal Plain series all the way from the Mississippi

valley, parallel with the Coastal border, to Virginia, and southern Maryland, north of which the deposits become less extensive and are represented in northern Maryland, Delaware, and Pennsylvania by only a few small remnants. In Virginia a broad belt extending from the Piedmont margin to the center of the Coastal Plain is covered by a mantle of Lafayette deposits in the inter-stream areas.

The deposits consist of clay, loam, sand, and gravel, the latter often highly ferruginous, and cemented into a compact iron-stone. The sediments were much less fully sorted than was the case in the earlier Tertiary formations, although the coarse sandy and gravelly materials are most common in the lower part and the loams most common in the upper part of the formation. The gravel, too, is often considerably decayed. The deposits frequently possess a characteristic orange color. The Lafayette formation has an average thickness of about 50 feet, but at times exceeds 75 feet.

A few fragments of molluscan shells have been reported from eastern Virginia but they are quite inadequate to determine the age of the deposits if they should ultimately prove to have come from beds of this horizon. The reference of the beds therefore to the Pliocene is based on the fact that they have been found overlying the Miocene, and that they are in turn older than the Columbia deposits of Pleistocene age which wrap about their margin. The discovery of authentic fossils of chronologic value is therefore necessary before the correlation can be regarded as satisfactory.

---

## THE QUATERNARY PERIOD.

### PLEISTOCENE.

---

#### *The Sunderland Formation.*

The Sunderland formation, so called from Sunderland, Calvert County, Maryland, wraps as a terrace about the Lafayette or, in case of its absence by erosion, the older formations of the Coastal Plain area throughout the middle Atlantic region. At the close of the Lafayette epoch the Coastal Plain region was elevated and the main drainage channels of the area were deeply cut, the coast

line standing far to eastward of its present position. The great Susquehanna River flowed through the channel now occupied by Chesapeake Bay, and passing the Capes, reached the sea far to the eastward.

With the advent of Sunderland time the sea filled the old channels far above the present level but fell short of the greater elevations of the western Coastal Plain district. As the water stood at this position, a fringing terrace was formed, such as we find at the present time co-extensive with the coast line of the tide water region. Just as in the case of the terrace forming today, this early Pleistocene terrace shelves off toward the main channels, and, by a slight depression seaward relative to the main land farther westward, the top of this terrace also slopes a few feet in the mile eastward. Its old surface has been extensively eroded over considerable areas, and its level character is less apparent than in the case of the later and the lower-lying Wicomico and Talbot.

The deposits consist of clay, sand, and gravel, with here and there ice-borne blocks that have been brought down the rivers by the streams from the mountains to the westward. The materials are for the most part poorly sorted although commonly the coarser sands and gravels are found in the lower part of the formation and the loams in the upper part. The beds seldom have a thickness exceeding 40 feet. A few leaves of recent types have been found in the Sunderland deposits in Maryland but none are reported from Virginia.

---

#### *The Wicomico Formation.*

The Wicomico formation, so called from the river of that name which enters the Potomac from the Maryland bank between Charles and St. Mary's counties, wraps about the Sunderland formation as a terrace at a lower level and from its less elevation and younger age has suffered less from erosion than has the Sunderland. It is found throughout the same general district as is the Sunderland but extends farther seaward, often occurring as a broad plain with a slight slope which stretches from the Sunderland border eastward.

The materials of the Wicomico are very similar to those of the Sunderland, and consist of clays, loams, sands, and gravels, with

here and there beds of peat and scattered ice-borne boulders. A bed of loam commonly forms the top of the formation with sand and gravels below, although the materials in general are poorly sorted. The sands are often cross-bedded, and occur in irregular lenses. The beds seldom exceed 40 feet in thickness and are commonly much less. Clay deposits containing leaf impressions of recent types are not unusual, but no animal remains have as yet been recognized.

---

*The Talbot Formation.*

The Talbot formation receives its name from Talbot County, Maryland, which is widely mantled with deposits of this age. In the same manner as the Wicomico formation wraps about the Sunderland so does the Talbot wrap about the Wicomico throughout the Coastal Plain. Its surface has an elevation landward of about 40 feet but this declines slowly seaward, until it falls nearly to sea level. Its level surface can be seen at this elevation throughout the eastern portions of the Coastal Plain on both sides of the Chesapeake Bay. On account of its slight elevation and late origin it has suffered much less from erosion than has any other formation of the Coastal Plain series.

The deposits consist of clays, loams, sands, and gravels, with many peat beds, and here and there ice-borne boulders. The physical and lithological characters are similar to the other formations of Pleistocene age, although at times the gravels seem less decayed than at the older horizons. This is, however, by no means universal. The deposits seldom exceed 30 feet in thickness.

The fossils found in the Talbot formation consist chiefly of leaf impressions, molluscan shells, and at some points of mammalian bones. The mollusca are chiefly marine and a number of localities are known in the Chesapeake Bay district where they occur in large numbers.

The Sunderland, Wicomico, and Talbot formations combined, constitute the Columbia group and possess many characters in common. The materials of which they are made come largely from the earlier Coastal Plain formations, although the streams flowing from the Piedmont and Appalachian districts have brought down additional supplies.

## RECENT.

The Recent deposits embrace chiefly those which are being laid down today over the submarine portion of the Coastal Plain and along the various estuaries and streams. To these must also be added such terrestrial deposits as talus, wind-blown sand, and humus. In short, all deposits which are being formed today under water or on the land by natural agencies belong to this division of geological time.

The Recent terrace now under construction along the present ocean shore line and in the bays and estuaries is the most significant of these deposits and is the last of the terrace formations which began with the Lafayette, the remnants of which today occupy the highest levels of the Coastal Plain, and which has been followed in turn by the Sunderland, Wicomico, and Talbot.

Beaches, bars, spits, and other formations are built up on this terrace belt and are constantly changing their form and position with the variations in currents and winds. Along the streams flood-plains are formed that in the varying heights of the water suffer changes more or less marked. On the land the higher slopes are often covered with debris produced by the action of frost and the heavy downpours of rain which form at times accumulations of large proportions known as talus and alluvial fans.

A deposit of almost universal distribution in this climate is humus or vegetable mold, which, being mixed with the loosened surface of the underlying rocks, forms our agricultural soils. The ultimate relationship therefore of the soils to the underlying geological formations is evident.

The deposit of wind-blown sands, more or less apparent everywhere, as may be readily demonstrated at every period of high winds, is especially marked along the sea coast, particularly in the vicinity of Cape Henry where sand dunes of large dimensions have been formed. Other accumulations in water and on the land are going on all the time and with those already described represent the formations of Recent time.

Part II

---

The Clays of the  
Virginia Coastal Plain

---

By HEINRICH RIES

## CHAPTER II.

### THE ORIGIN, PROPERTIES AND MODE OF OCCURRENCE OF CLAYS.

INTRODUCTORY.—Clay is one of the most curious and least understood of our common mineral products, and various investigators have spent much time in attempts to discover the causes of its peculiar properties. In some cases they have partially succeeded; in others it must be admitted that while they have partly solved the problem, they are nevertheless still very far from a complete and satisfactory interpretation of the phenomena discussed.

In the pages here devoted to a discussion of the properties of clay, nothing further is attempted than a description of these characters and their practical value. The scientific discussion of them will be left for the final report which will cover the entire state.

Man at a very early period in the earth's history discovered the peculiar qualities of the common substance known as clay. That its usefulness has steadily increased is evidenced by the fact that in 1904, the value of clay products made in the United States alone exceeded \$130,000,000; which was greater than the value of other important products such as gold, silver, copper and petroleum, and was only outranked by iron and coal. This being the case, we can justly regard clay as one of our most important mineral resources, although up to a few years ago it was quite neglected by both government and state surveys.

CLAY DEFINED.—The term clay is applied to a group of earthy materials occurring in nature, whose most prominent character is that of plasticity when wet. This peculiar property permits their being shaped into any desired form when moist, which shape they retain when dried. By exposing the clay to the heat of a fire, it becomes hard and rock-like, thus enabling us to render permanent the form given to it when green or soft. These are two important physical properties which make clay of such great value, but there are a number of minor characters which are also of some importance and will be discussed later.

To the unaided eye, clay usually appears so fine-grained that most of its component grains cannot be identified, although some particles of quartz, or small scales of mica are not infrequently recognizable. Microscopic examination, however, reveals the presence of a number of small mineral grains, many of which are under one one-thousandth of an inch in diameter. In addition to these there are particles of organic matter as well as other small bodies of non-crystalline character, which are classed as colloids, and may be of either organic or inorganic origin. The mineral fragments making up the bulk of the clay represent a variety of compounds in all stages of decomposition, but their properties and effects on the clay will be left until a later page.

#### ORIGIN OF CLAY.

So far as we know clay results primarily from the decomposition of other rocks, and very often from rocks containing an appreciable amount of the mineral feldspar. There are some rocks, however, that contain practically no feldspar which, on weathering, yield a most plastic clay. In all of these clays there is found a variable amount of the mineral kaolinite, which is of secondary origin, *i. e.*, it is derived from other minerals by decomposition. This is termed the *clay base*.

In order to trace the process of clay formation, let us take the case of granite, a rock which is commonly composed of three minerals, namely, quartz, feldspar, and mica. 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 there may be joint-planes formed by the contraction of the rock as it is 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 stone. Plant roots force their way into these cracks and, as they expand in growth, 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.

The rain water, however, acts in another way. It not only carries oxygen into the pores of the rock, but also acids in solution, the latter being gathered in part from the air, and in part from decaying vegetable matter. The result of this is that the oxygen and the acids attack many of the mineral grains of the rock and change them into other compounds. Some of these are soluble and can be carried off by the water circulating through the mass, but others are insoluble and are left behind. It will thus be seen that one effect of this action is to withdraw certain elements from the rock, and, the structure of the minerals as well as the rock being destroyed, it crumbles to a clayey mass.

The three minerals mentioned as being commonly present in granite are not equally affected, however, by the weathering agents. Thus the quartz grains are but slightly attacked by the soil waters, while the feldspar loses its lustre and changes slowly to a white, powdery mass, which is usually composed entirely of grains of kaolinite. The mica, if whitish in color, remains unattacked for a long time, and the glistening scales of it are often visible in many clays. If the mica is dark colored, due to iron in its composition, it rusts rapidly and the iron oxide, thus set free, may permeate the entire mass of clay and color it brilliantly. The kaolin deposits of Henry county, Virginia, contain much coarse mica, while the surrounding clay is brilliantly colored by iron-oxide liberated in the weathering of iron-bearing mica.

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; and (d) below this the nearly solid rock. In other words there is a gradual transition from the fully formed clay at the surface into the parent rock beneath (Fig. 1). A marked exception to this is found in clays formed from limestone, where the passage from clay to rock is 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 commonly of carbonate of lime, with a variable quantity of clay impurities, so that when the weathering agents attack the rock, the carbonate of lime is dissolved out by the surface waters, and the insoluble clay impurities are left behind as a mantle on the undissolved rock—the change from the 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.

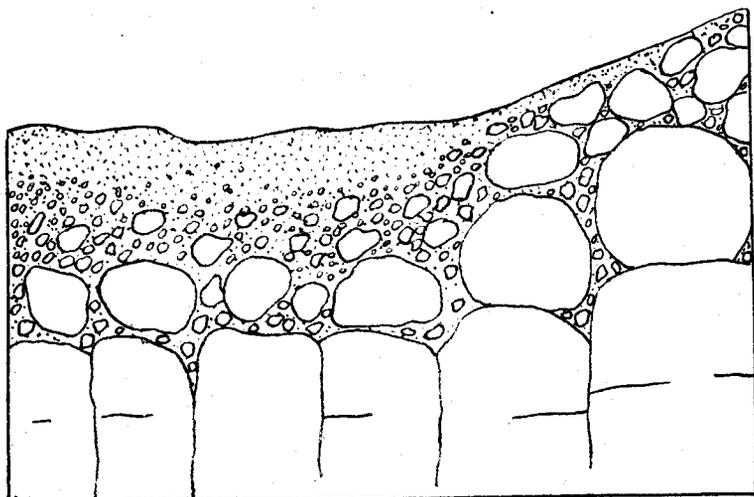


FIG. 1. Section showing passage from residual clay on surface to parent rock below. The clay is thinner on the slopes than in the depressions.

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

A residual clay formed from a rock containing little or no iron oxide is usually white, and is termed *kaolin*, and deposits of this type generally contain a high percentage of the mineral *kaolinite*. On the other hand, a residual clay derived from a rock containing much iron oxide will be yellow, red, or brown, depending on the iron compounds present. Between the pure white

clays and the brilliantly colored ones, others are found representing all intermediate stages, so that residual clays vary widely in their purity.

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. The Henry county kaolin deposits are of this type.

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 away 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 one, although they are not, strictly speaking, residual clays.

Residual clays, usually of impure character, are widely distributed over the southern portion of the United States, except in the Coastal Plain belt. In Virginia they are to be seen at many points throughout the Piedmont and Appalachian belts where the slopes are not too steep. Around Richmond and Petersburg, for example, the residual clay forms a mantle of variable thickness in the granite quarries, and in the regions underlain by schist

and shale (both easily decomposable rocks), it frequently occurs in masses of great thickness.

Residual clays are commonly highly colored by a large percentage of iron oxide, but in a few instances where they have been derived from a rock poor in iron-bearing minerals, the clay is light yellow or even white.

*Uses of Residual Clay.*—Owing to their gritty character, caused by the presence of numerous quartz fragments and impure nature, the majority of residual clays cannot be used for anything except common brick. There are, however, occasional deposits which, on account of their fine grain, are available for pottery manufacture; or others which are low in impurities, and can hence be used for making fire brick or even buff pressed brick.

The distribution of Virginia occurrences is left for a future report.

**SEDIMENTARY CLAYS.**—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 very 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 on the slopes is washed down and spread out over the bottom of the pit.

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.

The stratified character of the clay is not seen with equal clearness in all beds, and to the untrained eye may not always be apparent, but the sand grains and pebbles found in sedimentary clays are always more or less rounded, caused by a rubbing together of the particles while being transported. Plate II, Fig 2, shows a sedimentary deposit of loamy clay overlain by gravel.

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.

All sedimentary clays resemble each other in being stratified, but aside from this they may show marked irregularities in structure. (Fig. 2.)

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.

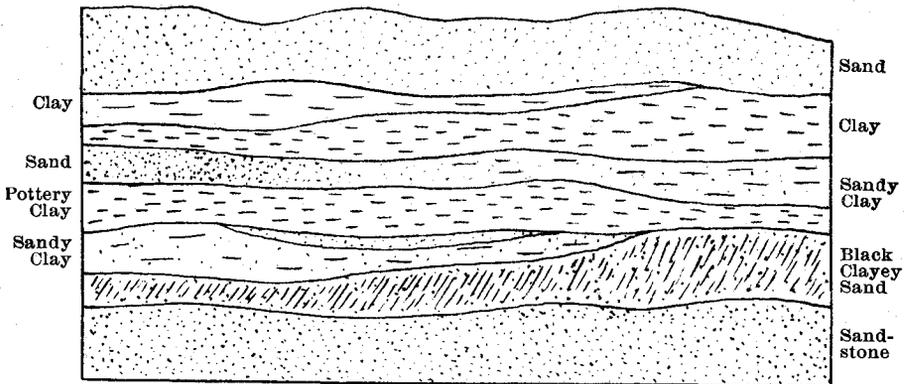


FIG. 2. Section showing how sedimentary clay beds may vary horizontally and vertically.

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. 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.

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.

The clays found south of Richmond, Sturgeon Point, Bermuda Hundred, City Point, etc., are in the same formation, and superficially they appear to be very similar; yet in burning they behave somewhat differently as to shrinkage, color, vitrifying qualities, etc. This is due to variations in both their chemical composition and physical character.

All the clays found in the Coastal Plain or Tidewater Belt of Virginia are of sedimentary origin. Those found in other parts of the State are either residual or sedimentary. The former are more abundant, but the latter are the ones more often worked.

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 (Pl. II, Fig. 1).

Such conditions as these are by no means uncommon in the Virginia Coastal Plain belt.

*Classification of Sedimentary Clays.*—Sedimentary clays are deposited under a variety of conditions which tend to influence not only the form of the deposit but in many cases its physical character. The different groups may be briefly referred to as follows:

1. **Marine Clays**, which include all 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 coarse materials can be deposited. This means that in a formation carrying marine clays, the clays may pass into the beds of sand as we go towards the ancient shoreline of the sea in which they were laid down.

Beds of marine clay may be of vast extent and great thickness, but will naturally show much 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 the sediment spreads 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 a 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.

2. **Estuarine Clays** 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. Estuarine clays often show sandy laminations, and are not infrequently associated with shore marshes. Deposits of this type are found in the coastal belt.

3. **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 laminae as to be readily overlooked, but causing the clay layers to split apart easily.

Clay beds of this type are not especially common in the Coastal Plain of Virginia, but in the areas to the west, are to be looked for in many depressions which have received the wash from the residual clays on the surrounding slopes. Their quality is variable.

4. **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 the 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 can not 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 a second being available only for common brick and tile.

Flood-plain clays may occur in the Coastal Plain but they are of little importance. They will be found, however, at many points in the Piedmont and Appalachian belts, and are sometimes worked for common brick at least.

**5. Drift or Boulder Clays** are tough, dense, gritty clays, often containing many stones, and represent ice transported material which has been largely ground to fine rock flour, through which are scattered pebbles and boulders. Such deposits are found only in those portions of the United States which were covered by the ice sheet during the glacial period. Glacial clays are, therefore, not found in Virginia. Some of the clays in the Manchester brick-yards (Pl. X, Fig. 2.) contains large boulders but these have probably been dropped in the clay by masses of floating ice.

---

## SECONDARY CHANGES IN CLAY DEPOSITS.

Changes often take place in clays subsequent to their deposition. These may be local or widespread, and in many cases they may either greatly improve the clay or else render it worthless. At a number of localities the entire deposit may have been altered so that it is difficult to tell what its original character was, but in others only a portion of the deposit has been altered, and one can easily trace the changes that have gone on.

The changes which take place in clay subsequent to its formation are of two kinds, namely, mechanical and chemical.

## MECHANICAL CHANGES.

FOLDING, TILTING AND FAULTING.—From what has been said regarding the origin of sedimentary clays, it has been seen that they were laid down under water, but the fact that they now appear at the surface indicates that the water has been drained off, either by the water level falling or the sea bottom being elevated. If the latter occurred, and such has been the case in Eastern Virginia, there was little likelihood that the elevation of all points over such a large area was the same, and such a differential uplift has produced a tilting or dipping of the beds towards the south-east.

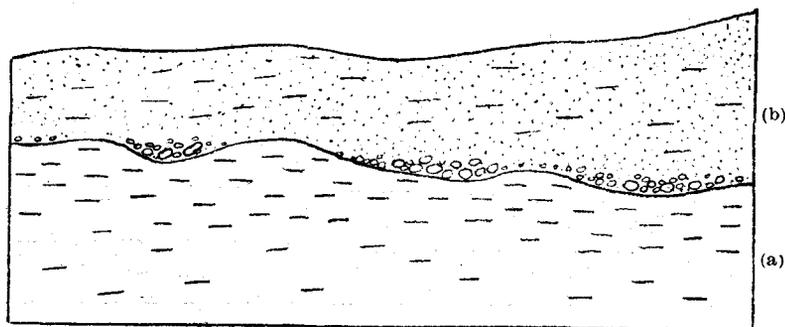


FIG. 3. Section showing clay bed (a), with uneven upper surface caused by erosion. The currents causing this deposited the pebbles in the hollows, and these were in turn covered by a bed of sandy clay (b).

Beds of clay and shale sometimes show folds or undulations. In the Coastal Plain clays of Virginia these are rarely seen, but in the shales of the Appalachian region they are by no means uncommon.

Where beds of clay or shale are bent into arches (anticlinal folds) (Fig. 7) and troughs (synclinal folds), (Fig. 8), 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. These considerations are of importance in prospecting for clays in central and western Virginia but they do not have to be considered in the Coastal Plain region.

Where a bed is not sufficiently elastic to bend under pressure, it breaks, and if, at the same time, the beds on the opposite side

of the break slip past each other, this displacement is termed *faulting*. 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. Faulting is not uncommon in some of the shale deposits of central and western Virginia but no evidence of it was observed in the Coastal Plain deposits.

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, these lower beds will be exposed only where stream valleys have been carved. (Fig. 5.)

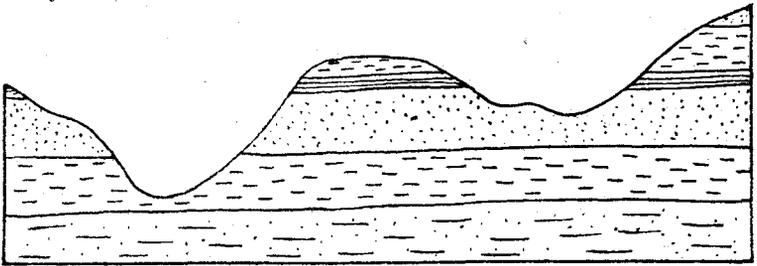


FIG. 4. Section in horizontally stratified beds of clay and sand. The lower beds are exposed in the deeper valleys.

If the beds are tilted or folded and the crest of the folds worn off, then the different beds will outcrop on the surface as parallel bands (Figs. 5 and 6), whose width of outcrop will decrease, with an increase in the amount of dip.

These facts are again especially applicable to the shaly clays of the Great Valley and Allegheny belt.

**EROSION.**—All land areas are being constantly attacked by the weathering agents (frost, rain, etc.), resulting in a crumbling of the surface rocks and the removal of 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 conditions, which may at first sight appear puzzling, but are nevertheless quite simple, when the cause of them is understood.

If the beds have a uniform dip, the conditions may be as indicated in Fig. 9. 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 3. If one did not know that the beds

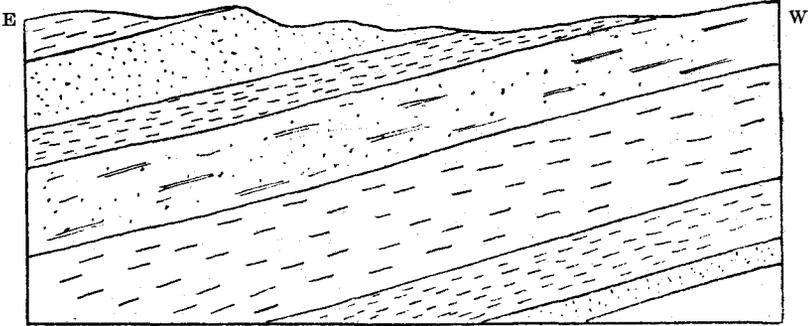


FIG. 5. East-west section showing outcropping beds of inclined strata.

rose in that direction it might be assumed that bed 1 passed into bed 3, 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.

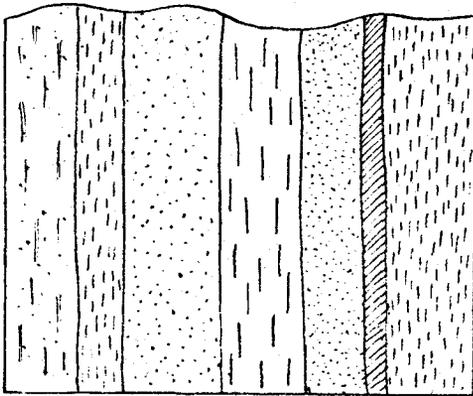


FIG. 6. Section of vertical beds.

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 with

certainly, for, as has been mentioned above, clay beds may thin out within a short distance.

It is not always possible to correlate clays by means of their position, and assume that in a region of but slightly tilted strata all those occurring at the same level are of the same age or *vice versa*.

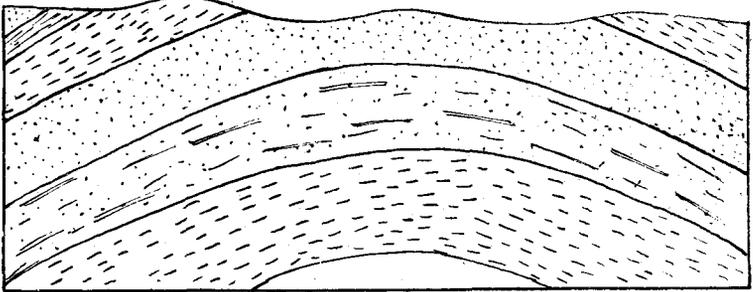


FIG. 7. Section of folded beds. The crest of the arch has been worn away, thus exposing several of the beds.

For example, let us consider a case like that shown in Fig. 4. Here we have a series of horizontally stratified clay and sand beds which have been eroded, but in some places the valleys which

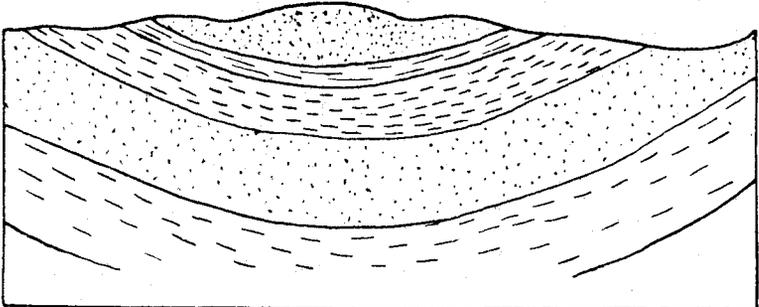


FIG. 8. Section of beds folded into a trough or syncline.

have been cut are much deeper than others. Now if this area were depressed so that the sea could fill the valleys and deposit a series of estuarine clays, these, although formed at the same time, would not be found at the same level after the sea receded. This is not an uncommon phenomenon in the Coastal

Plain region and makes it difficult to formulate a rule for prospecting clays belonging to any given formation. That is to say, if the clays of any one period were deposited at the same level, and had a uniform dip, we could map the line of outcrop and point out the elevation above sea level at which the beds were to be sought for in any given area, but since the clays were not always deposited on a plain surface, this cannot be done.

#### CHEMICAL CHANGES.

Nearly all clay deposits are affected, superficially at least, by the weather. 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

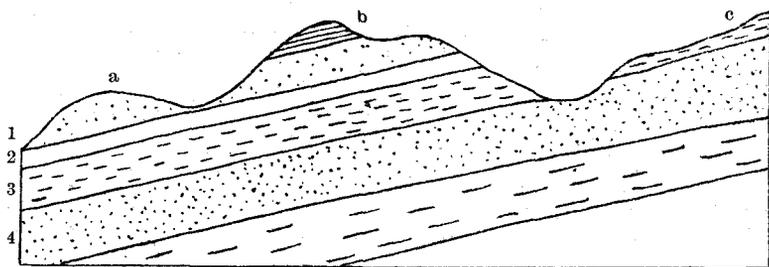


FIG. 9. Inclined beds, showing how they are found at continually higher levels if followed up their slope or dip.

or brown, such discoloration being 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 mineral 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.

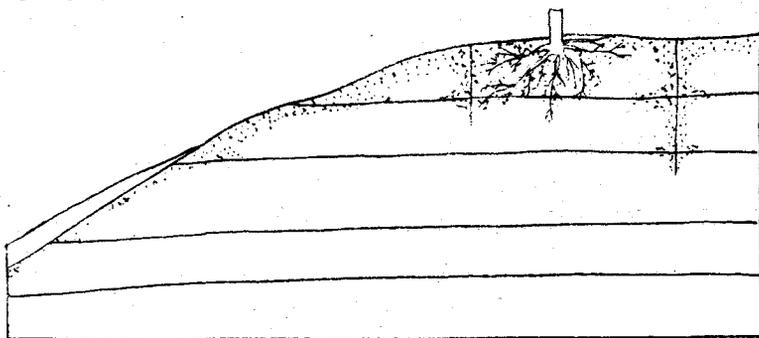


FIG. 10. Section illustrating how weathering penetrates a clay, working in deepest along joint planes, or roots.

Changes in color due to weathering can be distinguished from differences in color of a primary character by the fact that discoloration caused by weathering 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. 10.

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 role 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 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 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.

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 the upper layers of the deposit containing less lime carbonate than the lower ones, due to the solvent action of the percolating waters. This leaching action is especially noticeable in the case of residual clays formed from limestone or calcareous shales, where, during the decomposition or mellowing of the rock under weathering influences, the easily soluble carbonate of lime is removed by percolating waters, so that little or none is found in the residual clay. This is well shown by the two following analyses in which I represents the fresh limestone and II the residual clay derived from it.

	I	II
Silica ( $\text{SiO}_2$ ).....	4.13	33.69
Alumina ( $\text{Al}_2\text{O}_3$ ).....	4.19	30.30
Ferric oxide ( $\text{Fe}_2\text{O}_3$ ).....	2.35	1.99
Lime ( $\text{CaO}$ ).....	44.79	3.91
Magnesia ( $\text{MgO}$ ).....	.30	.26
Potash ( $\text{K}_2\text{O}$ ).....	.35	.96
Soda ( $\text{Na}_2\text{O}$ ).....	.16	.61
Water ( $\text{H}_2\text{O}$ ).....	2.26	10.76
Carbonic acid ( $\text{CO}_2$ ).....	34.10	0.00
Phosphoric acid ( $\text{P}_2\text{O}_5$ ).....	3.04	2.54
Manganous oxide ( $\text{MnO}$ ).....	4.33	14.98
	<hr/> 100.00	<hr/> 100.00

It is not to be understood that because the particular clay which this analysis represents the composition of runs high in manganese oxide, that all residual clays do.

SOFTENING.—Most weathering processes break up the clay deposits, either by disintegration or by leaching out some soluble

constituents that served as a binding 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.

Some of the pressed brick yards near Alexandria store up their clay, partly for this purpose, but partly as a means of blending the different kinds. Common brick manufacturers rarely follow this plan, it being done at but one yard in eastern Virginia.

**CONSOLIDATION.**—Some clays, and more especially sandy ones, become somewhat consolidated subsequent to their formation. This is commonly caused by a deposition of limonite (hydrous iron oxide) between the clay particles. In the majority of deposits, where such a change has occurred, the deposition of the limonite takes place in those portions of the clay where the water carrying it can enter, as in cracks, or locally porous parts of the mass. Very few instances of this were noticed in the Virginia Coastal Plain clays, but in the sandy beds accompanying them it was not uncommon. In some, as at Oldfield, the limonite has been deposited around plant rootlets, forming small, irregularly cylindrical concretions, from a quarter of an inch to two inches long.

**FORMATION OF SHALE.**—This is nothing more than a consolidated clay and its formation is properly referred to under this head. Many sedimentary clays, especially 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 these have sometimes been to transform or metamorphose the shale into slate or even mica-schist (where the metamorphism was intense), both of which are devoid of any plasticity when ground.

While many shales develop high plasticity, others are so gritty and coarse-grained that they possess little value for the manufacture of clay products. In Virginia, it is only the Paleozoic shales that, so far as known, possess any economic value. There are shales associated with the Triassic coals near Richmond, but these are so gritty and carbonaceous as to preclude their use for the manufacture of clay products. Some of the partially decomposed schists will also prove of value to the clay-worker.

### CHEMICAL PROPERTIES OF CLAY.

THE COMBINATION OF ELEMENTS IN CLAY.—Many chemical elements are found in the rocks of the earth's crust, yet only a few of them are widespread and important. But, by averaging up the analyses of several hundred rocks from all parts of the world, a fairly accurate estimate can be made of the average quantity of each element present. This has been done by F. W. Clarke, chief chemist of the United States Geological Survey, and the results obtained by him are given in the following table. The name of the element is given first, followed by its symbol in parenthesis, and then the average per cent.

*Table showing percentage of elements found in the earth's crust.*

Oxygen (O).....	47.02	Hydrogen (H).....	0.17
Silicon (Si).....	28.06	Carbon (C).....	0.12
Aluminum (Al).....	8.16	Phosphorus (P).....	0.09
Iron (Fe).....	4.64	Manganese (Mn).....	0.07
Calcium (Ca).....	3.50	Sulphur (S).....	0.07
Magnesium (Mg).....	2.62	Barium (Ba).....	0.05
Sodium (Na).....	2.63	Strontium (Sr).....	0.02
Potassium (K).....	2.32	Chromium (Cr).....	0.01
Titanium (Ti).....	0.41		

Of those mentioned in the above list, carbon and sulphur are the only ones ever found in the elementary state in clays. The others are usually found in combination with each other. Thus, for example, silicon unites with oxygen to form the compound known as silica, which consists of one atom of silicon and two atoms of oxygen, and which would be designated by the symbol  $\text{SiO}_2$ . Similarly, two of aluminum will unite with three of oxygen, forming the compound known as alumina and represented by the symbol  $\text{Al}_2\text{O}_3$ ; again, iron in similar combination may give either  $\text{FeO}$  or  $\text{Fe}_2\text{O}_3$ ; or  $\text{CaO}$  (lime) may be formed from calcium and oxygen. Carbon and oxygen form  $\text{CO}_2$ , known as carbon dioxide or carbonic acid gas. If the latter unites with  $\text{CaO}$ , we get a compound expressed by the symbol  $\text{CaCO}_3$ , and called lime carbonate;  $\text{CaO}$  and  $\text{SiO}_2$  may unite, giving  $\text{CaSiO}_3$ , which is called a silicate of lime because it is a compound containing calcium, silicon and oxygen.

The elements are divisible into two groups, the one known as acid elements, the other as basic elements or bases. The latter are commonly oxides of the metallic elements, and include  $\text{CaO}$  (lime),  $\text{MgO}$  (magnesia),  $\text{Al}_2\text{O}_3$  (alumina),  $\text{Fe}_2\text{O}_3$  (ferric oxide),  $\text{K}_2\text{O}$  (potash),  $\text{Na}_2\text{O}$  (soda). The acids and bases are strongly opposed in their characters, and, while there is little or no affinity between members of the same group, those of opposite groups show a marked affinity for each other. An acid, therefore, tends to unite with a base under favorable conditions, these conditions being either the presence of moisture or heat, both of which promote chemical activity and therefore combination. Compounds formed by the union of acid elements and basic elements are termed salts, and the different ones possess a different degree of permanence or destructibility. Thus, some exist only at low temperatures, and are broken up or pass off in gaseous form at a red heat, while others may form only at a temperature of redness or higher.

Clay contains a great many different chemical compounds of more or less definite chemical composition, and often having a definite form. Each of these represents a mineral species, possessing definite physical characters, which could be easily seen if the grains of clay were large enough. The latter is the case, however, with only a few of the scattered, coarse grains, which the material may contain, and, consequently, it is necessary to

use a microscope in order to identify the various mineral particles present in any clay, as even a powerful hand glass cannot ordinarily distinguish them.

### MINERALS IN CLAY.

Many different kinds of minerals are found in clay, but few of them are present in large amounts, and only a very small percentage of them are recognizable with the naked eye. Those most commonly found are quartz, feldspar, kaolinite, calcite, gypsum, mica, pyrite, dolomite, iron ores, hornblende, and rutile. Of these, quartz is probably always present, and often very abundant. Kaolinite is doubtless rarely wanting; calcite is common in the very calcareous clays.

*Quartz.*—This mineral, which chemically is silica, 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 still deeper water. Quartz may be colorless, but it is often colored superficially red or yellow by iron oxide. It breaks with a glassy, shell-like fracture, and is a very hard mineral, being seven in the scale of hardness. It will, therefore, scratch glass, and is much harder than most of the other minerals commonly found in clay, with the exception of feldspar. Quartz at times forms nodules, which have no crystalline structure and are termed flint, or chert, but these are not found in the Coastal Plain clays. They are not uncommon in some of the residual deposits found in Virginia.

*Feldspar.*—Feldspar is a mineral of rather complex composition, being a mixture of silica and alumina, with either potash, or with lime and soda, and occurring usually in red, pink or white grains. When fresh and undecomposed, the grains have a bright lustre, 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. Feldspar rarely occurs

in such large grains as quartz, and, furthermore, is not as lasting a mineral, being easily attacked by the weather or soil waters, and so decomposed to a whitish clay.

*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, because the light scaly character of the mineral keeps it in suspension, until it settles in quiet water with the clay particles.

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, and the black mica or biotite. The former is a silicate of alumina and potash, and the latter a silicate of alumina, iron oxide and magnesia. 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, rusts and decomposes much more rapidly on account of the iron oxide which it contains. The effect of mica in burning is mentioned under alkalies.

*Iron Ores*.—This title includes a series of iron compounds, which are sometimes grouped under the above heading, because they are the same compounds that serve as ores of iron, when found in sufficiently concentrated form to make them workable. The mineral species included under this head are:

Limonite ( $2\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$ )  
 Hematite ( $\text{Fe}_2\text{O}_3$ )  
 Magnetite ( $\text{Fe}_3\text{O}_4$ )  
 Siderite ( $\text{FeCO}_3$ )

The first is an oxide, with three parts of water (a hydrous oxide), the second and third are oxides, and the fourth is a carbonate.

*Limonite* has the same composition as iron rust. It occurs in various forms, and is often widely distributed in many clays, its presence 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 it forms concretionary masses of spherical or irregular shape.

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

*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 is liable to change to limonite.

*Siderite*, the carbonate of iron, may occur in clays in the following forms: (1) As concretionary masses of variable size and shape, often strung out in lines parallel with the stratification of the clay. These are more abundant in shales than in clay, and, if near the surface, the siderite concretions change to limonite on their outer surface. (2) In the form of crystalline grains, scattered through the clay and rarely visible to the naked eye. (3) As a film coating other mineral grains in the clay. This mineral will also change to limonite, if exposed to the weather.

*Pyrite*.—This is another mineral, which is not uncommon in some clays, and can often be seen by the naked eye. It is sometimes called *iron pyrites* or *sulphur*, and, chemically, it is a sulphide of iron ( $\text{FeS}_2$ ). It has a yellow color and metallic lustre, and occurs in large lumps, in small grains or cubes, or again in flat rosette-like forms.

When exposed to weathering action, pyrite is a rather unstable compound, that is to say, it tends to alter, and it changes from sulphide of iron ( $\text{FeS}_2$ ), to the sulphate of iron ( $\text{FeSO}_4$ ), by taking oxygen from the waters filtering into the clay. This also destroys its form, the yellow metallic particles changing to a white powdery mineral, which has a bitter taste and is soluble in water. Clays containing pyrite are not, as a rule, desired by the potters. None of the economically valuable clays examined in the Coastal Plain region were found to contain pyrite, but it will be found in many of the carboniferous shales of western Virginia.

*Glaucinite*.—This mineral, which is sometimes termed greensand, and in bulk, greensand marl, or simply marl (an incorrect

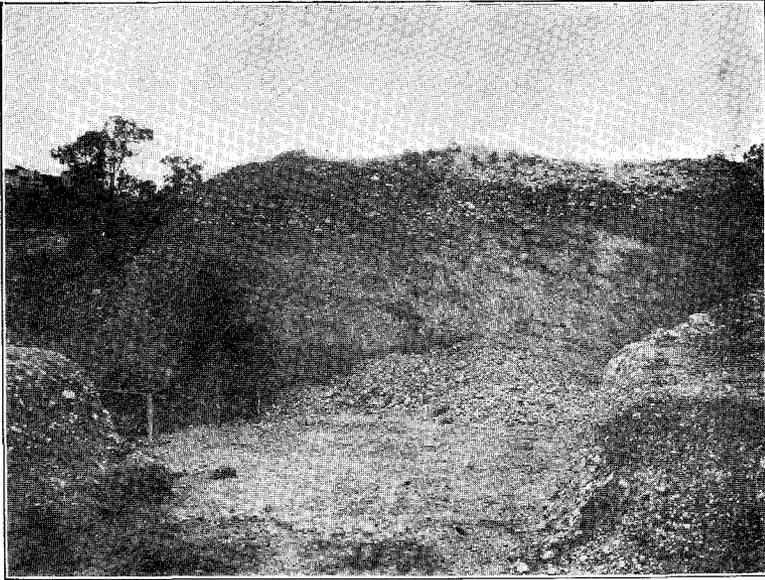
term) is an important constituent of some of the Virginia Coastal Plain clays. Chemically, it is a compound containing silica, potash, iron and water (a hydrous silicate of potash and iron), occurring in the form of greenish sandy grains. Its composition is often somewhat variable and it may contain other ingredients as impurities. Thus a sample from New Jersey analyzed: Silica, 50.70 per cent.; alumina, 8.03 per cent.; iron oxide, 22.50 per cent.; magnesia, 2.16 per cent.; lime, 1.11 per cent.; potash, 5.80 per cent.; soda, 0.75 per cent.; water, 8.95 per cent. It is an easily fusible mineral, and hence a high percentage of it is not desired in clay. None of the clays which are being worked contain it so far as known.

Glauconite clay is dug to some extent along the James river, southeast of City Point, but it is used in fertilizer manufacture and not in clay products.

*Kaolinite*.—This mineral is a compound of silica, alumina and water (a hydrated silicate of alumina), represented by the formula  $\text{Al}_2\text{O}_3, 2\text{SiO}_2, 2\text{H}_2\text{O}$ , which corresponds to a composition of silica ( $\text{SiO}_2$ ), 46.3 per cent.; alumina ( $\text{Al}_2\text{O}_3$ ), 39.8 per cent.; water ( $\text{H}_2\text{O}$ ), 13.9 per cent. It is rarely found in pure masses, but when isolated is found to be a white, pearly mineral, the crystals forming small hexagonal plates, which are often found to be collected into little bunches that can be separated by grinding. When the mineral *kaolinite* forms large masses, the name *kaolin* is applied to it. It is plastic, and is also highly refractory, fusing at cone 36. (See p. 75 under fusibility.) The amount of kaolinite present in clays varies, some white kaolins containing over 98 per cent. while other sandy impure clays may have less than 20 per cent.

Associated with kaolinite, there have been found one or more species of allied minerals which are all hydrated silicates of alumina. They are known as halloysite, rectorite, newtonite, allopheane, etc. Some of these have been found in the form of crystals, and others have not.

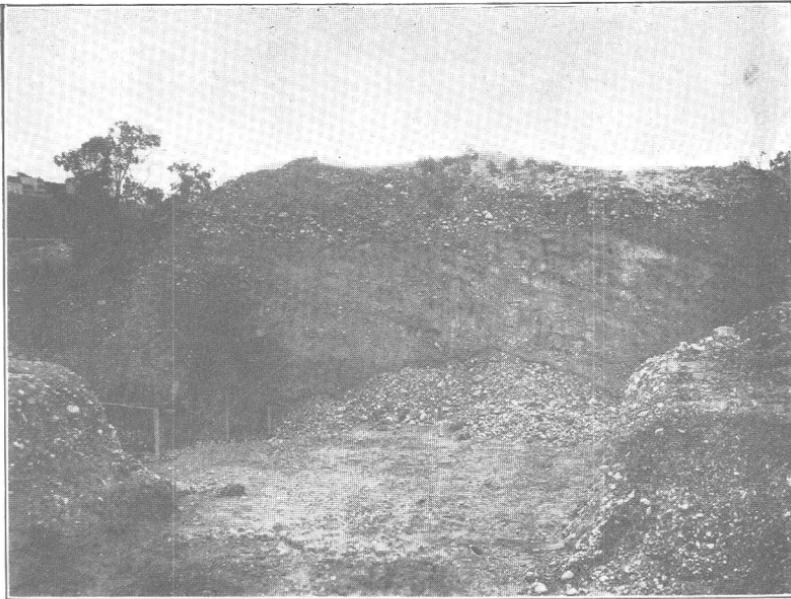
*Rutile*.—The oxide of titanium ( $\text{TiO}_2$ ) rutile is of widespread occurrence in clays, and is usually found on chemical analysis, when proper tests are made. Rutile grains can be seen under the microscope in many fire clays, and the analyses show the presence



A. Cross-bedded clay, sand and gravel. Harbaugh's Pit, Richmond.



B. Deposit of loamy clay overlain by gravel, showing sudden change of character often met with in sedimentary clay and sand deposits. Brower's Pit, Richmond.



A. Cross-bedded clay, sand and gravel. Harbaugh's Pit, Richmond.



B. Deposit of loamy clay overlain by gravel, showing sudden change of character often met with in sedimentary clay and sand deposits. Brower's Pit, Richmond.

ence of titanium oxide to the extent of nearly two per cent. 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 the clay is such that it should not be neglected, in the higher grades at least. It is possible, however, that some of the titanium found in clay, is present in some other form than rutile, such as leucoxene.

*Calcite*.—This mineral is composed of carbonate of lime, and, 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. When in grains large enough to be seen with the naked eye, it is found to be a translucent mineral with a tendency to split into rhombohedral fragments, due to the presence in it of several directions of splitting or cleavage. It is also soft enough to be easily scratched with a knife. Few clays contain grains of calcite sufficiently large to be seen with the naked eye, although in some the calcite, as well as some other minerals, may form concretions. The concretions, although lacking a granular or crystalline structure, would nevertheless give the acid test.

*Gypsum*.—This mineral, the hydrous sulphate of lime, contains lime (CaO, 32.6 per cent.), sulphuric acid (SO<sub>3</sub>, 46.6 per cent.), and water (H<sub>2</sub>O, 20.9 per cent.). It may occur in clays, even in large lumps. The only locality in the Coastal Plain where it was noted was in some clays near City Point on the James river. Here the gypsum forms nodules scattered through the mass, and the clays have no value either for clay products or as a gypsum proposition.

Gypsum when present in clay, and large enough to be visible without the use of a microscope, forms crystals or plate-like masses. It is much softer than calcite and can be scratched with the finger nail; has a pearly lustre, is transparent; and it does not effervesce with acid or vinegar. When heated to a temperature of 250°C. (482°F.), the gypsum loses its water of combination, and when burned to a still higher temperature, at least a part of the sulphuric acid passes off.

*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.

*Dolomite*.—Dolomite, the double carbonate of lime and magnesia, and also magnesite, the carbonate of magnesia, 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.

Judging from the very low percentage of magnesia in the Coastal Plain clays, there is but little dolomite or magnesite in them, indeed most of the magnesia which they contain is probably a constituent of mica.

### 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 complex forms. Thus, for example, calcium carbonate ( $\text{CaCO}_3$ ), if it were present, is not expressed as such, but, instead, is considered as broken up into carbon dioxide ( $\text{CO}_2$ ) and lime ( $\text{CaO}$ ), 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 the clay might be expressed as follows:

	Silica .....	( $\text{SiO}_2$ )
	Alumina .....	( $\text{Al}_2\text{O}_3$ )
	Ferric oxide .....	( $\text{Fe}_2\text{O}_3$ )
	Ferrous oxide .....	( $\text{FeO}$ )
	Lime .....	( $\text{CaO}$ )
	Magnesia .....	( $\text{MgO}$ )
Fluxing Impurities	Alkalies } Potash .....	( $\text{K}_2\text{O}$ )
	} Soda .....	( $\text{Na}_2\text{O}$ )
	Titanic oxide .....	( $\text{TiO}_2$ )
	Sulphur trioxide .....	( $\text{SO}_3$ )
	Carbon dioxide .....	( $\text{CO}_2$ )
	Water.....	( $\text{H}_2\text{O}$ )

In most analyses, the first seven of these and the last one are usually determined. The percentage of carbon dioxide is mostly small, and commonly remains undetermined, except in very calcareous clays. 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 black clays. The loss on ignition in the majority of *dry* 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.

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, 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, but all the analyses made for this report have been calculated in this way.

The facts obtainable from the ultimate analysis of a clay are the following:

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

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

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

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

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

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

7. The presence of several per cent. of both lime (CaO) and carbon dioxide (CO<sub>2</sub>) in the clay indicates that it is quite calcareous.

In the table below are given the analyses of a number of Virginia clays, in order to illustrate the variation in comparison which this class of materials shows. To this is added one calcareous clay from another state, as none of those described in this report run high in lime.

	1	2	3	4	5
Silica (SiO <sub>2</sub> ).....	46.38	57.26	55.33	25.72	41.86
Alumina (Al <sub>2</sub> O <sub>3</sub> ).....	39.76	28.97	25.69	5.83	10.70
Ferric oxide (Fe <sub>2</sub> O <sub>3</sub> ).....	.79	3.10	9.02	1.74	5.02
Lime (CaO).....	.44	.04	.22	1.01	14.33
Magnesia (MgO).....	.05	.19	.08	.11	2.81
Potash (K <sub>2</sub> O).....	1.80	1.40	2.57	1.31	} 2.80
Soda (Na <sub>2</sub> O).....	.20	.42	.25	.64	
Water (H <sub>2</sub> O).....	10.26	8.44	6.00	3.55	*8.00
Titanic acid (TiO <sub>2</sub> ).....	.28	.14	.81	.06	.....
Carbonic acid (CO <sub>2</sub> ).....	.....	.....	.....	.....	14.50

\* Includes moisture.

1. Washed Kaolin, Oak Level, Henry Co.
2. Clay from between Stafford and Fredericksburg.
3. Red Clay, Fredericksburg.
4. Clay from South Shore of Rappahannock River, near Layton.
5. A Calcareous Clay.

RATIONAL ANALYSIS.—This method has for its object the determination of the percentage of the different mineral compounds present in the clay, such as quartz, feldspar, kaolinite, etc., and

of titanium oxide to the extent of nearly two per cent. The terial. Most kaolins and other high-grade clays consist chiefly of kaolinite, quartz, and feldspar, the kaolinite forming the finest particles of the mass, while the balance is quartz, feldspar, and perhaps 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 these three, quartz is nearly infusible, nonplastic, has 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 kaolinite and, when the percentage of it does not exceed 1 or 2 per cent., it can be neglected. Some chemists include mica under clay substance, but it does not seem wise, as it differs somewhat in its properties from kaolinite.

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 high-grade clays, in which the variation of the ingredients can only be within comparatively narrow limits. For ordinary purposes the ultimate analysis is of greater value.

Clays may agree closely in their ultimate analysis, and still differ widely in their rational composition.

---

#### 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.**—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 is found 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 so as that contained in the kaolinite. A better practice is to use the term *sand* to include quartz and silicate minerals, other than kaolinite, and which are not decomposable by sulphuric acid. In the majority of 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.

In the Virginia clays analyzed for this bulletin the average silica percentage was 68.74 per cent. with a minimum of 51.12 per cent. and a maximum of 85.72 per cent.

With the exception of kaolinite, all of the silica-bearing minerals 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 anti-shrinkage agent, which greatly diminishes the air shrinkage, plasticity and tensile strength of the 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 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.

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, and each changes its form but little up to its fusion point. 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 anti-shrinkage agent only at low temperatures. Variation in the size of the grain may affect these results.

**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; sulphides, pyrite; carbonates, siderite.

In some, such as the oxides, the iron is combined only with oxygen, and is better prepared to enter into the 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 sulphur of the pyrite and the carbonic acid 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 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.

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

AMOUNT OF FERRIC OXIDE IN CLAYS.

Kind of Clay	Minimum	Maximum	Average
Brick clays .....	0.126	32.12	5.311
Fire clays .....	0.01	7.24	1.506
Kaolins.....	.....	6.87	1.29

In the Virginia Coastal Plain clays analyzed, ferric oxide ranged from 1.74 per cent. to 10.70 per cent. with an average of 5.33 per cent.

*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. The intensity of color is not always an indication of the amount of iron present, since the same quantity of iron oxide 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 in Burned Clay.**—All of the iron ores will, in burning, change to the form of oxide, provided the clay is not completely vitrified, and so affect the color of the burned material; 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: 1st, the amount of iron in the clay; 2d, the temperature of burning; 3d, condition of the iron oxide; and 4th, the condition of the kiln atmosphere.

1. Clay perfectly free from iron oxide burns white. If a small quantity, say 1 per cent., is present, a slightly yellowish tinge is imparted to the burned material, but an increase in the iron content up to 2 or 3 per cent. produces a buff product, while 4 or 5 per cent. of iron oxide makes the clay burn red.

2. If a clay is heated to 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.

3. Among the oxides of iron two kinds are recognized, known respectively as the ferrous oxide ( $\text{FeO}$ ) and ferric oxide ( $\text{Fe}_2\text{O}_3$ ). In the former 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 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 oxidization. In magnetite both ferrous and ferric iron are present, but in siderite the ferrous iron alone occurs. In the ultimate chemical analysis the iron is usually determined as ferric oxide, no effort being made to find out the quantity present as carbonate or sulphide.

Iron passes rather readily from the ferric to the ferrous form, and *vice versa*. Thus, if there is a deficit of oxygen in the inside of the kiln the iron does not get enough oxygen and the ferrous compound results, but the latter changes at once to the ferric condition, if sufficient air carrying oxygen is admitted. Similarly, if ferric oxide is present in a clay containing considerable carbonaceous matter, the latter will, if it cannot get enough oxygen from the kiln atmosphere, take it from the ferric oxide and so reduce the latter to the ferrous condition. The same change may be produced by smoky fires. The necessity for recognizing these two forms of iron oxide is 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 may produce yellow, cherry red, violet, blue and black. Seger 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.

It is found sometimes that bricks after burning show a black core, due to the iron in the centre of the brick being prevented from oxidizing (see Carbon in clay), but this should not be confused with the black coloration seen on the ends of many arch

brick, which is caused by the slagging action of the impurities in the fuel.

4. Since the stage of oxidization 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 oxide is 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 followed 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 the ferrous state or if silica is present. 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.

**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. The 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.

**LIME.**—Lime is found in many clays, and in the low-grade ones may be present in large quantities at times. 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, garnet.
3. Sulphates. Gypsum.

When the ultimate analysis of a clay shows several per cent. of lime ( $\text{CaO}$ ), it is usually present as an ingredient of lime carbonate ( $\text{CaCO}_3$ ), and in such cases its presence can be easily detected by effervescence if a drop of muriatic acid or vinegar is put on the clay. When present in this form it is apt to be finely divided, although it may occur as concretions or limestone pebbles.

When lime is present as an ingredient of silicate minerals, such as those mentioned above, its presence cannot be detected with muriatic acid. It is doubtful, however, if many calcareous clays contain much lime in this combination and the fact that practically all limy clays, so indicated on chemical analysis, give a strong test with muriatic acid, strengthens this theory. 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. 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  $450^\circ\text{C}$ . ( $842^\circ\text{F}$ .) and  $600^\circ\text{C}$ . ( $1112^\circ\text{F}$ .), the carbon dioxide ( $\text{CO}_2$ ) does not seem to go off until between  $600^\circ\text{C}$ . ( $1112^\circ\text{F}$ .) and  $725^\circ\text{C}$ . ( $1562^\circ\text{F}$ .). In fact, it more probably passes off between  $850^\circ\text{C}$ . ( $1562^\circ\text{F}$ .) and  $900^\circ\text{C}$ . ( $1652^\circ\text{F}$ .). 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.

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 ware.

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 compound 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 impart instead a buff color to the burned clay. 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  $41.6^{\circ}\text{C}$ . ( $76^{\circ}\text{F}$ .) 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.

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 per cent. or 25 per cent. of lime carbonate, provided it is in a finely divided condition and a vitrified ware is not attempted. If, however, that much 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 brick, common earthenware, roofing, tile and some terra cotta.

*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 as lime carbonate does. They serve as fluxes, but do not cause a rapid softening of the clay.

*Effect of Gypsum.*—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, is a hydrous sulphate of lime. In calcining gypsum for making plaster of Paris, the chemically combined water is driven off at 250°C., and it has probably been usually taken for granted that the sulphuric acid was driven off at a red heat, but only a portion of it volatilizes up to a temperature of 1300°C.

The range of lime, as determined from a series of clays, is as follows:

AMOUNT OF LIME IN CLAYS.

Kind of Clay	Minimum	Maximum	Average
Brick clays .....	0.024	15.38	1.513
Pottery clays .....	0.011	9.90	1.098
Fire clays .....	0.03	15.27	0.655
Koalins.....	tr.	2.58	0.47

In the Virginia Coastal Plain clays it ranged from 0 per cent. to 1.46 per cent. with an average of 0.45 per cent.

MAGNESIA (MgO) rarely occurs in clay in larger quantities than 1 per cent., and, so far as known, none of the Virginia clays are exceptions to this rule. When present, its source may be any one of several classes of compounds, i. e., silicates, carbonates, or sulphates.

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 or rusts very easily, and its chemical combination being thus destroyed, the magnesia is set free in the form of a soluble compound, which may be retained in the pores of the clay. Hornblende is not an uncommon constituent of some clays, especially in those which are highly stained by iron, and which have been derived from dark-colored igneous rocks. Like biotite, it alters rather rapidly on exposure to the weather. Dolomite, the mixed 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 ( $\text{FeS}_2$ ), 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.

The effect of magnesia is quite different from that exerted by the lime, for mixtures containing magnesia do not vitrify suddenly, as in the case of calcareous clays.

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

#### AMOUNT OF MAGNESIA IN CLAYS

Quality	Minimum	Maximum	Average
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 Virginia Coastal Plain clays it ranged from .05 per cent. to 1.18 per cent. with an average of .38 per cent.

**ALKALIES.**—The alkalis include potash ( $\text{K}_2\text{O}$ ), soda ( $\text{Na}_2\text{O}$ ), and ammonia ( $\text{NH}_3$ ). There are other alkalis but they are probably of rare occurrence in clays.

The amount of total alkalis contained in a clay varies from a mere trace in some to 7 per cent. or 9 per cent. in others. The range of alkalis in several classes of clays was determined to be as follows:

#### AMOUNT OF TOTAL ALKALIES IN CLAYS

	Range	Average
Kaolins .....	0.1 - 6.21	1.01
Fire clays .....	0.048- 5.27	1.46
Pottery clays .....	0.52 - 7.11	2.06
Brick clays .....	0.17 -15.32	2.768

In the Virginia Coastal Plain clays potash ranged from .75 per cent. to 3.13 per cent. with an average of 2.05 per cent.; and soda from .22 per cent. to 1.33 per cent. with an average of .72 per cent.

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.

Several common minerals may serve as sources of the alkalies. Feldspar may supply either potash or soda or both. 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 4-12 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.

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 clay, they appear to act as a flux at different temperatures, according to the size of the grains. If very finely ground, the mica seems to vitrify at as low a temperature as cone 4, but if the scales are larger, they will retain their individuality up to cone 8, or even 10.

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 is set free and forms soluble compounds.

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 than it otherwise could. In the manufacture of porcelain, white earthenware, encaustic tiles and other wares made from white-burning clays, and possessing an impervious body, feldspar is an important flux.

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

TITANIUM 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. Among the titanium-bearing minerals, the commonest is *rutile*, which is an oxide of titanium ( $\text{TiO}_2$ ), containing 60 per cent. of metallic titanium and 40 per cent. of oxygen. So far as known it is never found in clays in sufficiently large grains to be visible to the naked eye, although a microscopic examination may often show its presence in the form of little needles or grains. Its frequent occurrence is, no doubt, due to the fact that it is quite resistant to weathering. Leucoxene might also be present.

Very few State Geological Surveys, in investigating their clay resources, have made special determinations of this mineral, but in an investigation of the clays of New Jersey, made in 1877, Prof. Cook found that in 21 clays examined it ranged from 1.06 to 1.93 per cent. In a series of Pennsylvania fire clays the percentage of titanium oxide ranged from 0.87 per cent. to 4.62 per cent.

In the Virginia Coastal Plain clays analyzed, titanium oxide ranged from 0 per cent. to 1.95 per cent. with an average of .44 per cent.

Titanium serves as a flux at high temperatures, and even 1 or 2 per cent. may lower the fusion point of a refractory clay slightly. It is also probable that it may cause some of the yellowish tint seen in some clays which have an exceedingly low percentage of iron. So far as we know a small percentage of it does not materially affect the qualities of the lower grade clays.

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

*Mechanically admixed water.*—The mechanically admixed water is that held in the pores of the clay by capillary action, and filling all the spaces between the clay grains. When these spaces are 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 and sands, for these reasons, show high power 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. It is not the highly aluminous ones, however, that always absorb the most water. The total quantity found in different clays varies greatly. 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.

Water held mechanically in a clay will pass off partly by evaporation in air, and it 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, and this part of the burning process is referred to as water-smoking or steaming. The shrinkage that takes place when the mechanical water is driven off varies, ranging 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 considerably in drying, there is often danger of their cracking, especially if rapidly dried, owing to the rapid escape of 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. Black coring is indirectly affected by it. (See Carbon.)

*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.). This combined water may be expelled from several minerals such as kaolinite which contains nearly 14 per cent.; white mica or muscovite with 4 to 5.5 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 alumina contained in the clay. In pure or nearly pure kaolin there is nearly 14 per cent. Other clays contain varying amounts, ranging from nearly 14 per cent. down to 3 per cent. 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 sometime after all the volatile substances have been driven off.

**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 often undergone subsequent changes which imparted to it an asphaltic or 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 it is commonly found in surface clays of recent origin. Organic matter of this character rarely affects the color of the raw clay and it burns out so easily, that it causes but little trouble; then too, it is not present in large quantity, rarely exceeding one 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 by it. It is found in some clays and in

many shales, especially in those associated with coal seams, and in the shales which are worked may range anywhere from 0 to 10 per cent. If in excess of 10 per cent. the shales are not workable. Even 5 to 6 per cent. cause much trouble in burning.

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

EFFECTS OF CARBON IN CLAY.—Only the second and third of the kinds 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 certainty.

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.

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. In burning a clay one of the aims is to get the iron into the ferric condition, so as to fully develop its coloring property. As long as any carbonaceous matter remains there is little or no chance for the iron to oxidize, and, consequently, the carbon must be burned out.

What the manufacturer needs to do, then, is this: First, water smoke the clay; second, burn the carbon out; and third, oxidize the 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 resulting from the combustion of the fuel will supply none. Moreover, the brick or ware must be sufficiently porous to

permit these oxidizing gases to enter and perform their task, which means that this must be done before the clay enters the period of vitrification and the pores begin to close up, due to a shrinkage and fusion of the mass.

What then is the best temperature at which this can be performed? The experiments of Orton and Griffin\* have shown that from 800°C. and 900°C. is the best temperature interval. Below this the oxidation of the carbon does not proceed as rapidly and above this there is danger of vitrification beginning and the oxidation process being stopped.

The method of procedure would, therefore, be to thoroughly watersmoke the ware, then raise the heat as rapidly as possible to a temperature between 800°C. and 900°C. and hold it there until the black core is entirely gone.

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. Fineness of grinding also assists it. In case the oxidation is not complete, and the pores of the clay close up before all the carbon is burned off, the expansion of the gases given off by the carbon will bloat the clay as soon as it becomes soft, and this may even be followed by complete fusion of the mass. 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.

*Black coring in Virginia clays.*—The only clays of the series tested from the Coastal Plain, which showed a serious tendency to black core, were those from the Miocene south of Chester. These, if used, would require careful treatment. The blue clays at Suffolk

---

\*Second Report of Committee on Technical Investigation, Indianapolis, 1905.

also require plenty of air in the earlier stages of burning, but little serious trouble is experienced with them.

*Effect of water on black coring.*—It is often stated by brick makers, 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 temperature of 800°C. 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 the brick begins to vitrify before it is all driven out.

---

### PHYSICAL PROPERTIES OF CLAY.

THE PHYSICAL PROPERTIES OF CLAY discussed here are plasticity, tensile strength, shrinkage, fusibility, texture, color, slaking and absorption.

**PLASTICITY.**—As already stated, this property is peculiarly characteristic of clays, and by virtue of it they can be shaped into any desired form. The cause of it need not be discussed here, but will be left to a future report on the Virginia clays of the Piedmont and Mountain belts.

Clays, as is well known, vary widely in their plasticity, some very sandy ones being of low plasticity or lean, while others are highly plastic or fat. Although scientists have not yet been able to satisfactorily explain the cause of plasticity, the clay-worker finds it possible to alter it to some extent. Thus a very plastic clay can be rendered less so by mixing it with sand, or a lean clay can often have its plasticity increased by washing.

**TENSILE STRENGTH.**—The tensile strength of a clay is the resistance which it offers to rupture on being pulled apart when air-dried. It is an important property by virtue of which the unburned clay ware is able to withstand shocks and strains of handling and probable shrinkage in drying. Through it, also, the clay is able to carry more or less nonplastic material which may be added to reduce the shrinkage. The tensile strength is not to be regarded as an index to the plasticity. Some clays of high tensile

strength show a high plasticity, but all do not. Others of low tensile strength are often highly plastic to the feel.

The tensile strength is measured by moulding the tempered clay into briquettes of similar form and dimensions to those made for testing cement and, when they are thoroughly air-dried, pulling them apart in a suitable testing machine. The cross section of the briquettes when moulded 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 in two. 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. In order to prevent this it is necessary to put some soft material, such as asbestos, pasteboard or rubber between the inner surface of the clip jaws and the sides of the briquette. If the briquettes are moulded 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.

In testing the Virginia clays 12 briquettes were made of each sample, and the average of these taken. In case a briquette broke very low on account of a flaw, it was not averaged in.

The tensile strength of clay briquettes is expressed in pounds per square inch, but, since the briquettes shrink in drying, the strength actually obtained will be less than that for one square inch, and the result must be increased in proportion to the amount the briquette has shrunk.

Practically all kinds of clay, excepting kaolins, show great variation in their tensile strength. The latter are always of low strength, but the former may be either low or high. In the Virginia Coastal Plain clays tested the tensile strength ranged from 34 pounds to 300 pounds per square inch.

**SHRINKAGE.**—All clays shrink in drying and burning, the former loss being termed the air shrinkage, and the latter the fire shrinkage.

*Air shrinkage.*—When a mass of clay is mixed with water, each of the grains of clay can be considered as being surrounded by a film of liquid, which may prevent the grains from coming into close or actual contact. As soon as the wet, moulded mass is set aside to dry, however, evaporation of the water contained in the pores of the clay begins, and, as it passes off, 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 spaces left between the grains, and these will hold moisture, which cannot be driven off except by gentle heating. The air shrinkage may, therefore, cease before all the water has passed off.

The amount of air shrinkage is usually low in lean clays, and high in very plastic ones, for the reason that the latter absorb considerable water in mixing, which they give off in drying. At the same time, however, it must be noted that all clays which require 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 material. Soft-mud bricks may shrink more than stiff-mud ones, because in the latter cases less water is added to the clay, and it is melted under greater pressure. At the same time the shrinkage of many soft-mud bricks is low, because much sand is often added to the clay. The low shrinkage of some sandy clays is seen in the case of Nos. 1322 and 1363, in the table opposite page 131.

While coarse or sandy clays shrink less than fine-grained ones, they may sometimes absorb considerable water, especially if they are silty in their character, but the fact that their pores are much coarser allows the water to escape rapidly, and thus often permits more rapid drying. The cracking of some fine-grained clays in drying is due partly to the surface shrinking more rapidly than the interior, because the evaporation there is greatest. As the outer portion of the product cannot stretch, it must pull apart and crack.

*Fire shrinkage.*—All clays shrink during some stage of the burning operation, even though they may expand slightly at certain temperatures. The fire shrinkage varies within wide limits,

the amount depending partly on the quantity of volatile elements, such as combined water, organic matter and carbon dioxide present in the clay, and partly on the texture. It reaches a maximum when the clay vitrifies, but does not increase uniformly up to that point, and, in fact, is very irregular. Thus a certain amount of shrinkage takes place when the combined water begins to pass off, namely, at 400°C. (752°F.), and an additional amount occurs at higher temperatures, but not apparently the result of contraction following volatilization of some of the elements.

Wherever the fire shrinkage is given in this report, it refers to the linear shrinkage occurring during burning, and is expressed in terms of the length of the bricklet when molded. Thus, if the fire shrinkage at cone 1 is given as 4 per cent., it means that the amount of fire shrinkage at that cone is 4 per cent. of the length of the bricklet when freshly molded.

Referring to the samples tested for the present report (see table, opposite page 131), Nos. 1300 and 1335 have a low fire shrinkage on account of their sandy character; No. 1356 has a high fire shrinkage, owing to its highly plastic character; Nos. 1313 and 1326 show the increase in shrinkage up to the point of vitrification, beyond which the clay begins to swell somewhat as shown by the decreased fire shrinkage.

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 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 enable 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 of the common brickyards in the State, the writer has seen numbers of bricks split open during the burning because of one 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.

**FUSIBILITY.**—When clays are heated to a temperature of 1000°C. they show little or no fire shrinkage, but there is another important change which takes place, namely, expulsion of volatile matter, such as, chemically combined water contained in kaolinite, limonite, or mica. In this interval much carbonaceous matter, if present, also burns off.

The rapidity with which the latter is driven from the clay depends on its condition, that is to say whether it is present as volatile carbon or fixed carbon. Of these two, the former burns off more readily.

From what has just been said, it is easily seen that the volatilization of the substances mentioned must necessarily leave the clay in a somewhat porous condition, until fire shrinkage again begins at 1000°C. or a little above.

A clay should, therefore, be heated slowly up to 600°C. (1112°F.) but from that point up to 1000°C. (1832°F.), the temperature can be rapidly raised unless much carbonaceous matter is present. (See Carbon in Clay.)

When a clay is heated, its hardness slowly increases until it finally reaches that of steel, or, in other words, cannot be scratched by a knife. This simply means that the clay particles have become so cemented by fusion that none can be scratched loose by a piece of steel.

The reaching of steel hardness by the clay does not mean vitrification, for many bricks are still porous. The temperature at which steel hardness occurs varies with the character of the material,

in pure easily fusible clays becoming so at a low temperature, such as cone 05, while others, such as kaolins, will not become steel-hard before cone 5 or possibly 8.\*

Most clays soften slowly when heated, until they melt completely or run. Since the softening of clays under heat is comparatively slow, three stages are commonly recognized, termed, respectively, incipient fusion, vitrification, and viscosity.

The first of these expresses a condition in which the clay has softened just enough to make most of the particles stick together.

The second indicates a condition in which the clay particles have softened sufficiently to pack together and practically close up all the pores; and since it represents a stage of greatest compactness it is also the point of maximum shrinkage.

The third represents a stage at which the clay particles have softened so that the mass no longer holds its shape but runs.

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 very gradual.

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 377.7°C. (700°F.) to 444.4°C. (800°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.

It is of considerable practical importance to have the points of incipient fusion 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 vitrification and viscosity is great, it will be safer to bring the ware up to a condition of 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 vitrification seems to be midway between that of incipient fusion and viscosity, but in others it is not.

---

\* For description of Seger cones see p. 79 of this chapter.

Several of the Pleistocene Coastal Plain clays, which were tested, soften with sufficient slowness to warrant their trial for vitrified products.

*Temperature of fusion.*—The temperature at which a clay fuses depends on: (1) The amount of fluxing impurities; (2) the condition of the fluxes; (3) the size of the grains; and (4) the condition of the kiln atmosphere, whether oxidizing or reducing.

1. 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. All fluxing impurities do not, however, act with equal energy, some being more active than others.

2. The condition of chemical combination may also affect the result. Thus lime, for example, will induce a fluxing action in clay at a lower temperature if present in the form of carbonate of lime than as silicate.

3. The size of the mineral grains in clay undoubtedly exerts more effect than some investigators have been willing to admit. Other things being equal, a fine-grained clay will fuse at a lower temperature than a coarse-grained one, for the reason that when the particles of a clay 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 the temperature between vitrification and viscosity still remain to be satisfactorily explained, but it probably depends on the relative amounts of fluxes and nonfluxes and the size of grain of the latter.

4. 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 an abundance of the latter.

*Classification of clays based on fusibility.*—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 proposed will meet with universal approval.

The following classification of clays, based on refractoriness, has been suggested by the writer:\*

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.

3. *Semi-refractory clays*, those whose fusion point lies between cone 27 and 30 inclusive.

4. *Clays of low refractoriness*, those whose fusion point lies between cone 20 and 26 inclusive.

5. *Nonrefractory clays*, fusing below cone 20.

The Coastal Plain clays in Virginia all fall in groups 4 and 5.

*Determination of fusibility.*—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, thermo-electricity, spectro-photometry, etc.

---

\* New Jersey Geological Survey, Final Report 1904, Vol. VI, p. 100.

*Seeger cones.*—These test pieces consist of a series of mixtures of clay 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. Seeger, 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 No. 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 36, which 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. The result is that there is now a series of 58 numbers, the fusion point of the lowest being 590°C. (1094°F.), and that of the highest 1850°C. (3362°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.

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 full series can be obtained from Messrs. Seeger and Cramer, of Berlin, for \$0.01 each (or about two and one-half cents apiece, including duty and expressage), or numbers .010 to 35 can be obtained for \$0.01 each from Prof. E. Orton, Jr., of Ohio State University, Columbus, Ohio. The table of fusing points of these cones and their composition is given below:

*Composition and fusing points of Seger cones.*

Number of cone.	Composition.		Fusion Point.			
			Cent.	Fahr.		
022	0.5 Na <sub>2</sub> O	}	2	SiO <sub>2</sub>	590	1094
	0.5 Pb O		1	B <sub>2</sub> O <sub>3</sub>		
021	0.5 Na <sub>2</sub> O	} 0.1 Al <sub>2</sub> O <sub>3</sub>	2.2	SiO <sub>2</sub>	620	1148
	0.5 Pb O		1	B <sub>2</sub> O <sub>3</sub>		
020	0.5 Na <sub>2</sub> O	} 0.2 Al <sub>2</sub> O <sub>3</sub>	2.4	SiO <sub>2</sub>	650	1202
	0.5 Pb O		1	B <sub>2</sub> O <sub>3</sub>		
019	0.5 Na <sub>2</sub> O	} 0.3 Al <sub>2</sub> O <sub>3</sub>	2.6	SiO <sub>2</sub>	680	1256
	0.5 Pb O		1	B <sub>2</sub> O <sub>3</sub>		
018. Dull red heat	0.5 Na <sub>2</sub> O	} 0.4 Al <sub>2</sub> O <sub>3</sub>	2.8	SiO <sub>2</sub>	710	1310
	0.5 Pb O		1	B <sub>2</sub> O <sub>3</sub>		
017	0.5 Na <sub>2</sub> O	} 0.5 Al <sub>2</sub> O <sub>3</sub>	3.0	SiO <sub>2</sub>	740	1364
	0.5 Pb O		1	B <sub>2</sub> O <sub>3</sub>		
016	0.5 Na <sub>2</sub> O	} 0.55 Al <sub>2</sub> O <sub>3</sub>	3.1	SiO <sub>2</sub>	770	1418
	0.5 Pb O		1	B <sub>2</sub> O <sub>3</sub>		
015	0.5 Na <sub>2</sub> O	} 0.6 Al <sub>2</sub> O <sub>3</sub>	3.2	SiO <sub>2</sub>	800	1472
	0.5 Pb O		1	B <sub>2</sub> O <sub>3</sub>		
014	0.5 Na <sub>2</sub> O	} 0.65 Al <sub>2</sub> O <sub>3</sub>	3.3	SiO <sub>2</sub>	830	1526
	0.5 Pb O		1	B <sub>2</sub> O <sub>3</sub>		
013	0.5 Na <sub>2</sub> O	} 0.7 Al <sub>2</sub> O <sub>3</sub>	3.4	SiO <sub>2</sub>	860	1580
	0.5 Pb O		1	B <sub>2</sub> O <sub>3</sub>		
012. Cherry red heat	0.5 Na <sub>2</sub> O	} 0.75 Al <sub>2</sub> O <sub>3</sub>	3.5	SiO <sub>2</sub>	890	1634
	0.5 Pb O		1	B <sub>2</sub> O <sub>3</sub>		
011	0.5 Na <sub>2</sub> O	} 0.8 Al <sub>2</sub> O <sub>3</sub>	3.6	SiO <sub>2</sub>	920	1688
	0.5 Pb O		1	B <sub>2</sub> O <sub>3</sub>		
010	0.3 K <sub>2</sub> O	} 0.2 Fe <sub>2</sub> O <sub>3</sub>	3.5	SiO <sub>2</sub>	950	1742
	0.7 CaO		0.3	Al <sub>2</sub> O <sub>3</sub>		
09	0.3 K <sub>2</sub> O	} 0.2 Fe <sub>2</sub> O <sub>3</sub>	3.55	SiO <sub>2</sub>	970	1778
	0.7 CaO		0.3	Al <sub>2</sub> O <sub>3</sub>		
08	0.3 K <sub>2</sub> O	} 0.2 Fe <sub>2</sub> O <sub>3</sub>	3.60	SiO <sub>2</sub>	990	1814
	0.7 CaO		0.3	Al <sub>2</sub> O <sub>3</sub>		
07	0.3 K <sub>2</sub> O	} 0.2 Fe <sub>2</sub> O <sub>3</sub>	3.65	SiO <sub>2</sub>	1010	1850
	0.7 CaO		0.2	Al <sub>2</sub> O <sub>3</sub>		
06	0.3 K <sub>2</sub> O	} 0.2 Fe <sub>2</sub> O <sub>3</sub>	3.70	SiO <sub>2</sub>	1030	1886
	0.7 CaO		0.3	Al <sub>2</sub> O <sub>3</sub>		
05	0.3 K <sub>2</sub> O	} 0.2 Fe <sub>2</sub> O <sub>3</sub>	3.75	SiO <sub>2</sub>	1050	1922
	0.7 CaO		0.3	Al <sub>2</sub> O <sub>3</sub>		
04	0.3 K <sub>2</sub> O	} 0.2 Fe <sub>2</sub> O <sub>3</sub>	3.80	SiO <sub>2</sub>	1070	1958
	0.7 CaO		0.3	Al <sub>2</sub> O <sub>3</sub>		
03	0.3 K <sub>2</sub> O	} 0.2 Fe <sub>2</sub> O <sub>3</sub>	3.85	SiO <sub>2</sub>	1090	1994
	0.7 CaO		0.3	Al <sub>2</sub> O <sub>3</sub>		
02	0.3 K <sub>2</sub> O	} 0.2 Fe <sub>2</sub> O <sub>3</sub>	3.9	SiO <sub>2</sub>	1110	2030
	0.7 CaO		0.3	Al <sub>2</sub> O <sub>3</sub>		
01	0.3 K <sub>2</sub> O	} 0.2 Fe <sub>2</sub> O <sub>3</sub>	3.95	SiO <sub>2</sub>	1130	2066
	0.7 CaO		0.3	Al <sub>2</sub> O <sub>3</sub>		
1	0.3 K <sub>2</sub> O	} 0.2 Fe <sub>2</sub> O <sub>3</sub>	4	SiO <sub>2</sub>	1150	2102
	0.7 CaO		0.3	Al <sub>2</sub> O <sub>3</sub>		
2	0.3 K <sub>2</sub> O	} 0.2 Fe <sub>2</sub> O <sub>3</sub>	4	SiO <sub>2</sub>	1170	2138
	0.7 CaO		0.4	Al <sub>2</sub> O <sub>3</sub>		
3	0.3 K <sub>2</sub> O	} 0.5 Fe <sub>2</sub> O <sub>3</sub>	4	SiO <sub>2</sub>	1190	2174
	0.7 CaO		0.5	Al <sub>2</sub> O <sub>3</sub>		
4	0.3 K <sub>2</sub> O	} 0.5 Al <sub>2</sub> O <sub>3</sub>	4	SiO <sub>2</sub>	1210	2210
	0.7 CaO		0.5	Al <sub>2</sub> O <sub>3</sub>		
5	0.3 K <sub>2</sub> O	} 0.6 Al <sub>2</sub> O <sub>3</sub>	5	SiO <sub>2</sub>	1230	2246
	0.7 CaO		0.6	Al <sub>2</sub> O <sub>3</sub>		

*Composition and fusing points—Continued.*

Number of cone.		Composition.		Fusion Point.	
				Cent.	Fahr.
6.....	0.3 K <sub>2</sub> O } 0.7 CaO }	0.7 Al <sub>2</sub> O <sub>3</sub>	{ 6 SiO <sub>2</sub>	1250	2282
7.....	0.3 K <sub>2</sub> O } 0.7 CaO }	0.7 Al <sub>2</sub> O <sub>3</sub>	7 SiO <sub>2</sub>	1270	2318
8.....	0.3 K <sub>2</sub> O } 0.7 CaO }	0.8 Al <sub>2</sub> O <sub>3</sub>	8 SiO <sub>2</sub>	1290	2354
9. White heat.....	0.3 K <sub>2</sub> O } 0.7 CaO }	0.9 Al <sub>2</sub> O <sub>3</sub>	9 SiO <sub>2</sub>	1310	2390
10.....	0.3 K <sub>2</sub> O } 0.7 CaO }	1.0 Al <sub>2</sub> O <sub>3</sub>	10 SiO <sub>2</sub>	1330	2426
11.....	0.3 K <sub>2</sub> O } 0.7 CaO }	1.2 Al <sub>2</sub> O <sub>3</sub>	12 SiO <sub>2</sub>	1350	2462
12.....	0.3 K <sub>2</sub> O } 0.7 CaO }	1.4 Al <sub>2</sub> O <sub>3</sub>	14 SiO <sub>2</sub>	1370	2498
13.....	0.3 K <sub>2</sub> O } 0.7 CaO }	1.6 Al <sub>2</sub> O <sub>3</sub>	16 SiO <sub>2</sub>	1390	2534
14 Bright white heat.....	0.3 K <sub>2</sub> O } 0.7 CaO }	1.8 Al <sub>2</sub> O <sub>3</sub>	18 SiO <sub>2</sub>	1410	2570
15.....	0.3 K <sub>2</sub> O } 0.7 CaO }	2.1 Al <sub>2</sub> O <sub>3</sub>	21 SiO <sub>2</sub>	1430	2606
16.....	0.3 K <sub>2</sub> O } 0.7 CaO }	2.4 Al <sub>2</sub> O <sub>3</sub>	24 SiO <sub>2</sub>	1450	2642
17.....	0.3 K <sub>2</sub> O } 0.7 CaO }	2.7 Al <sub>2</sub> O <sub>3</sub>	27 SiO <sub>2</sub>	1470	2678
18.....	0.3 K <sub>2</sub> O } 0.7 CaO }	3.1 Al <sub>2</sub> O <sub>3</sub>	31 SiO <sub>2</sub>	1490	2714
19.....	0.3 K <sub>2</sub> O } 0.7 CaO }	3.5 Al <sub>2</sub> O <sub>3</sub>	35 SiO <sub>2</sub>	1510	2750
20.....	0.3 K <sub>2</sub> O } 0.7 CaO }	3.9 Al <sub>2</sub> O <sub>3</sub>	39 SiO <sub>2</sub>	1530	2786
21.....	0.3 K <sub>2</sub> O } 0.7 CaO }	4.4 Al <sub>2</sub> O <sub>3</sub>	44 SiO <sub>2</sub>	1550	2822
22.....	0.3 K <sub>2</sub> O } 0.7 CaO }	4.9 Al <sub>2</sub> O <sub>3</sub>	49 SiO <sub>2</sub>	1570	2858
23.....	0.3 K <sub>2</sub> O } 0.7 CaO }	5.4 Al <sub>2</sub> O <sub>3</sub>	54 SiO <sub>2</sub>	1590	2894
24.....	0.3 K <sub>2</sub> O } 0.7 CaO }	6.0 Al <sub>2</sub> O <sub>3</sub>	60 SiO <sub>2</sub>	1610	2930
25.....	0.3 K <sub>2</sub> O } 0.7 CaO }	6.6 Al <sub>2</sub> O <sub>3</sub>	66 SiO <sub>2</sub>	1630	2966
26.....	0 K <sub>2</sub> O } 0.7 CaO }	7.2 Al <sub>2</sub> O <sub>3</sub>	72 SiO <sub>2</sub>	1650	3002
27.....	0.3 K <sub>2</sub> O } 0.7 CaO }	2.0 Al <sub>2</sub> O <sub>3</sub>	200 SiO <sub>2</sub>	1670	3038
28.....		Al <sub>2</sub> O <sub>3</sub>	10 SiO <sub>2</sub>	1690	3074
29.....		Al <sub>2</sub> O <sub>3</sub>	8 SiO <sub>2</sub>	1710	3110
30.....		Al <sub>2</sub> O <sub>3</sub>	6 SiO <sub>2</sub>	1730	3146
31.....		Al <sub>2</sub> O <sub>3</sub>	5 SiO <sub>2</sub>	1750	3182
32.....		Al <sub>2</sub> O <sub>3</sub>	4 SiO <sub>2</sub>	1770	3218
33.....		Al <sub>2</sub> O <sub>3</sub>	3 SiO <sub>2</sub>	1790	3254
34.....		Al <sub>2</sub> O <sub>3</sub>	2.5 SiO <sub>2</sub>	1810	3290
35.....		Al <sub>2</sub> O <sub>3</sub>	2 SiO <sub>2</sub>	1830	3326
36.....		Al <sub>2</sub> O <sub>3</sub>	2 SiO <sub>2</sub>	1850	3362

Dazzling white heat.....

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. In actual use they are placed in the kiln at a point where they can be watched through a peep-hole, 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 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.

The cone numbers used in different branches of the clay working industry are as follows:

Common brick.....	010—01
Hard-burned, common brick.....	1— 2
Buff front brick.....	6— 8
Hollow blocks and fireproofing.....	03— 1
Terra cotta.....	04— 7
Conduits.....	7— 8
White earthenware.....	8— 9
Fire bricks.....	9—12
Porcelain.....	11—13
Red earthenware.....	010—05
Stoneware.....	6— 8

While the temperature of fusion of each cone number 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 thermo-electric 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 peep-hole, the latter should not be opened wide during the burning, lest a cold draft strike the cones, and a skin forms on its surface and interferes with its bending. Moreover, one set of cones cannot be used to regulate an entire kiln, but several sets should be placed in different portions of the same kiln. One advantage possessed by a cone over trial pieces is that the cone can be watched through a small peep-hole, while a larger opening must be made to draw out the trial piece. If the cones are heated too rapidly, especially those containing a large percentage of iron, they are apt to blister.

The best results with cones are obtained in closed kilns. They are not of much service in scove kilns, for the reason that the temperature in these is apt to be more or less irregular, there being no good means of watching them, and they are liable to be touched by cold drafts. If placed in such kilns, they should be carefully enclosed to protect them from flashing or drafts of cold air.

*Thermo-electric pyrometer.*—This pyrometer, which is the only one that will be described in this report, 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 thermo-electric couple. This consists of two wires, one of platinum and the other of an alloy of 90 per cent. platinum and 10 per cent. rodium. The two are fastened together at one end, while the two free ends are connected with a galvanometer which measures the intensity of the current. That portion of the wires which is inserted into the furnace or kiln is placed within two fire-clay 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.

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.

Thermo-electric 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 thermo-electric pyrometer costs about \$180; and the price, delicacy of the instrument, and lack of realization of its importance, have 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.).

**TEXTURE.**—By the texture of a clay is meant its size of grain. 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.

If it is desired to measure the size of all the grains found in the clay, some more delicate method of separation becomes necessary. In many clays the grains cohere more or less, forming compound ones, and these have to be disintegrated by some preliminary treatment, such as boiling, or, better still, by agitating.

**COLOR.**—An unburned clay owes its color commonly to some iron compound or carbonaceous matter; a clay free from either of these being white. Carbonaceous matter will color a clay gray or

black, depending on the quantity present; 3 to 4 per cent. being usually sufficient to produce a deep black. A sandy clay will, however, be more intensely colored by the same quantity than one with many clay particles.

Iron oxide colors a clay yellow, brown, or red, depending on the form of oxide present. The greenish color of many of the clay marls is due to the presence of the mineral glauconite. The iron coloration is, however, often concealed by the black coloration due to the carbonaceous matter. It is often more or less difficult to make even an approximate estimate of the iron content in a clay from its color.

Thus, for example, the bluish-black Miocene clay, collected from along the Atlantic Coast-Line Railway south of Chester, burns to a bright red color.

The color of a green or raw clay is not always an indication of the color it will be when burned. Red clays usually burn red; deep yellow clays burn red or buff; 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. Calcareous clays are often either red, yellow or gray, and may burn red at first, but turn yellow or buff as vitrification is approached.

**SLAKING.**—When a lump of clay is thrown into water it falls to pieces or slakes but the rapidity with which this takes place varies greatly in different clays. Open, porous, sandy ones fall rapidly to a powdery mass; others may spall or chip off slowly when immersed; while still others either do not slake at all, or only after long soaking. The slaking property is one of some practical importance, as easy slaking clays temper more readily, or, if the material is to be washed, it disintegrates more rapidly in the long washer.

**SPECIFIC GRAVITY.**—The specific gravity of a clay stands in more or less close relation to the density of its mineral particles, and affects its weight per cubic foot, but most clays do not vary much in their specific gravity, which ranges commonly from about 1.80 to 2.60. That is they weigh 1.80 to 2.60 times as much as an equal amount of water.

## CHEMICAL AND PHYSICAL PROPERTIES OF THE COASTAL PLAIN CLAYS IN VIRGINIA.

Having discussed the chemical and physical properties of clays in general, it may be well to summarize those of the Virginia clays. During the course of the field work all the known deposits were visited and samples collected from many of them for physical tests and chemical analyses. Not a few of these deposits are being worked, and the question may be asked whether it pays to submit these to examination. In many cases it does, for the reason that the results of such a study suggests additional uses for the clay. At the present time the Virginia Coastal Plain clays are used for little else than the manufacture of common brick. For this purpose the clay is commonly burned at a very low temperature, sometimes under cone 010, which is not sufficiently high to bring out the vitrifying qualities of the material.

PHYSICAL PROPERTIES.—The clays collected were all tested for: (1) Amount of water required to work them up; (2) slaking qualities; (3) plasticity by feel; (4) grit; (5) air shrinkage; (6) tensile strength; (7) fire shrinkage, color, and per cent. of absorption at seven cones, namely 010, 05, 03, 1, 3, 5, 8.

The amount of water required for mixing ranged from 18.7 per cent. to 62.4 per cent., with an average of 26.5 per cent. The maximum was shown by a sample of diatomaceous earth, which is very silty in its character, and the majority absorbed between 20 and 25 per cent. of water, which is not excessive.

Most of the clays tested slake fast or moderately fast, so that they temper rather easily. The plasticity is variable, depending usually on the amount of silt or sand present, but in many of the Pleistocene clays it is excellent, and entirely sufficient to permit of their being worked in an auger or a dry-press machine. At present, soft-mud machines, or hand methods unfortunately find the greatest favor.

The grit content of some of the Coastal Plain clays is considerable, in others it is very low, and even in the bank there may be variations from place to place. Not all of the clays of the same formation show uniformity in grade, those at one point being quite sandy; those at another point being quite free from sand. The air shrinkage of the different samples tested ranged from 1.6

per cent. to 14 per cent., with an average of 8.2 per cent.; and even in the sandy ones the air shrinkage was not low. At the same time it is in most cases not sufficiently high to cause any trouble.

The tensile strength of the clays tested ranged from 41.2 pounds per square inch up to 300.9 pounds per square inch with an average of about 130 pounds. Few of them had a high tensile strength and very few of them showed a very low tensile strength, so that in most cases the bonding power is entirely sufficient for the uses to which they are liable to be put. Considering the burning qualities of the clays we find that the majority of those tested burned to a red body, only three yielding a cream colored or buff product. These three were respectively a clay from Oldfield on the James river (Lab. No. 1312), a whitish clay from between Stafford and Fredericksburg (Lab. No. 1352), and a buff clay from southeast of Wilmont (Lab. No. 1365). As already stated, all of the others burned red or red-brown, the color increasing with the intensity of the fire.

When burned at cone 010 the fire shrinkage of nearly all was under 1 per cent., but the absorption as seen from the tabulated tests was in most cases not excessive, that is to say, the absorption of many of them at this cone is between 15 and 20 per cent., which is no more than that shown by many common brick of good strength. In examining the tables of the tests made at other cones it is noticed that the clays usually show a gradual shrinkage up to their points of vitrification, after which they begin to expand slightly. Some of the clays burned to a very dense body at a comparatively low cone. A few examples of this are given below.

Locality	Cone	Absorption Per Cent.
1 Mile North of Bermuda Hundred.....	1	0.12
Broadway.....	1	1.7
6 Miles South of Richmond.....	1	1.5
Sturgeon Point.....	1	2.80
Suffolk, Drab Clay.....	1	1.50

A clay on the Williamsburg road near Richmond (Lab. No. 1330) showed an absorption of only 5.65 when burned at as low a cone as 03, and one from the Ball property six miles south of Richmond (Lab. No. 1316) had only 4.7 absorption at cone 03. It is probable

that clays burning as dense as these at such low heats could perhaps be used in the manufacture of paving brick or possibly even common stoneware.

**CHEMICAL PROPERTIES.**—A complete chemical analysis was made of each sample for the purpose of determining the silica, alumina, iron oxide, lime, magnesia, potash, soda, titanite oxide, and water. Examining the silica contents, first we notice that many of the clays show a somewhat high silica percentage, and this would lead us to suppose that they had a very low air shrinkage which, however, is not always the case, as much of the silica seems to be present in the form of fine silt, which would reduce the air shrinkage less than if it were there as coarse sand grains. The silica content ranged from 51.12 up to 85.72, with an average of 68.74 per cent. Some of those running highest in silica are samples of diatomaceous earth which should not perhaps be classed with the clays, but it is done for the reason that the material is interbedded with the clay deposits and often is more or less clayey in its character, sometimes even passing into a bed of clay. The percentage of alumina ranged from 5.83 to 28.97 with an average of 16.62, and in many the percentage of alumina is somewhat higher than it often is in brick clays. The highest alumina content, namely, 28.97 was shown by the Miocene clay collected between Stafford and Fredericksburg at a point about six miles east of north from the latter town. The lowest alumina percentage was found in a greenish gray clay which outcrops along the bank of the Rappahannock river about 1 mile south of Layton on the property of Mr. Beverley. This clay, which is pretty gritty, had a very low tensile strength, and on account of its highly siliceous nature its fire shrinkage was very low, and, in fact, at cone 010 it swelled slightly. Its siliceous character and its low fire shrinkage were accompanied, as one might expect, by a high absorption.

Turning to the iron oxide percentages we find that these range from 1.74 to 10.70 with an average of 5.33 per cent. In almost every case the percentage of iron shown by the analyses indicates its red burning color, although there are one or two which are slightly misleading. Thus, for example, a gray clay from Oldfield (Lab. No. 1312) burns to a somewhat buff color, although it has an iron content of 3.49. The reason for this is probably due

to the fact that the iron is not uniformly distributed in the clay, a condition which cannot be told from the chemical analysis. Again, a clay from Suffolk (Lab. No. 1343) tends to burn to a somewhat buff color, although it has 3.17 per cent. of iron. The sample of clay from the House Bank southeast of Wilmont (Lab. No. 1365) burns to a pink cream at low temperatures but above cone 1 its color begins to deepen somewhat. This on analysis showed but 2.42 per cent. of iron.

It is interesting to note that nearly all of the clays tested contained a variable but usually small quantity of titanite oxide, which ranged from 0 up to 1.95 per cent. with an average of .44 per cent.

As an example of the variation which may occur in clays in different parts of the same bank, we can take numbers 1334, 1335, and 1336 of the table. These three clays all occur in the same bed, and the one grades into the other. No. 1334 works all right, gives a good color, and makes a good brick. No. 1335 is less satisfactory, for it does not give as sound a brick. No. 1336 is a very sandy clay, and makes a porous brick that lacks in ring. For purposes of comparison the physical tests and chemical analyses are given in parallel columns.

The difference in behavior of these clays is brought out quite well in the physical tests. The greater sandiness and low plasticity of No. 1336 is quite marked; it also required less water for mixing than No. 1334, but about the same quantity as 1335. The air shrinkage decreases with the increase in the sand contents of the clay, No. 1334 being the least gritty and No. 1336 the most sandy. The same applies to the tensile strength or bonding power, that of 1336 being but little over half that of 1334.

When we examine the results of the fire tests, similar differences are found. No. 1334 burns to a brighter red color and denser body than either of the other two, and also has a higher fire shrinkage. The very sandy one which yields porous brick swells slightly at cone 010 and above that shows no shrinkage up to cone 5, above which it begins to diminish slowly in size.

The chemical analyses, although less expressive than the physical tests, nevertheless, show some differences. Thus we notice the increase in total silica from 1334 to 1336, and the decrease in alu-

	1334	1335	1336
Color.....	light brown	gray	gray
Water required.....	24.2	18.7	18.7
Slaking.....	mod. fast	fast	fast
Plasticity.....	fair	fair	low
Grit.....	sandy	sandy	sandy
Air shrinkage.....	8.3	6.0	5
Average tensile strength.....	144.2	105.1	79.8
<i>Cone 010</i>			
Fire shrinkage.....	.3	0	s. s.*
Color.....	light red	pink	pink
Absorption.....	17.7	15.7	15.08
<i>Cone 05</i>			
Fire shrinkage.....	1.6	.3	s. s.*
Color.....	light red	pink	light red
Absorption.....	14.7	14.5	14.0
<i>Cone 03</i>			
Fire shrinkage.....	3	1.3	0
Color.....	light red	light red	light red
Absorption.....	21.1	12.2	13.9
<i>Cone 1</i>			
Fire shrinkage.....	4.3	1.3	0
Color.....	red	light red	red
Absorption.....	8.2	10.3	12.90
<i>Cone 3</i>			
Fire shrinkage.....	5	2.6	0
Color.....	dark red	mottled red	light red
Absorption.....	6.6	9.3	12.3
<i>Cone 5</i>			
Fire shrinkage.....	4.6	2.3	0
Color.....	red gray	red	red
Absorption.....	5.0	7.86	10.91
<i>Cone 8</i>			
Fire shrinkage.....	5.0	3.6	1.3
Color.....	red brown	light brown	lt. brown
Absorption.....	.21	.31	6.50
Silica (SiO <sub>2</sub> ).....	69.75	74.55	77.78
Alumina (Al <sub>2</sub> O <sub>3</sub> ).....	17.13	15.43	12.84
Ferric oxide (Fe <sub>2</sub> O <sub>3</sub> ).....	4.67	3.07	3.05
Lime (CaO).....	.53	.43	.40
Magnesia (MgO).....	.31	.65	.29
Potash (K <sub>2</sub> O).....	1.89	1.42	1.69
Soda (Na <sub>2</sub> O).....	.56	1.16	.44
Titanic oxide (TiO <sub>2</sub> ).....	.06	.22	.20
Water (H <sub>2</sub> O).....	5.07	3.03	3.24
Total fluxes.....	7.96	6.73	5.87

\*s. s.—Slightly swelled.

mina in the same direction. The brighter color burning quality of 1334 is due to a higher percentage of ferric oxide.

Bricks are sometimes made from clays running as high in silica as 1336 does, or even higher, but the product is usually porous and weak, and from the series analyzed and tested for this bulletin,

one might assume that 75 per cent. silica is as high as it is wise to go.

It will be noticed that most of the clays have to be burned up to cone 1 to show what they are really good for, as below this the majority are quite porous. In this connection it is interesting to note that of two clays, the one showing the lower absorption at one cone will not show the same condition at a higher cone; in other words they do not always densify at the same rate in the same temperature interval. Compare 1306 and 1330.

---

### CHAPTER III.

#### EXPLOITING AND MINING CLAYS.

**PROSPECTING FOR CLAYS.**—While the methods used in searching for clays are simple, still, if the work is not thoroughly done, deposits are often easily overlooked.

*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 hill slopes, or where natural or artificial cuts have been made. The washing out of gullies by heavy rains; the cutting of a stream valley; railroad cuts and 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, until they reach the top of some impervious clay stratum, 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. In the Coastal Plain area, the best exposures are usually found along the rivers, such as the James, Appomattox, Rappahannock, York, etc., but even

here the banks become so low as the coast is approached, that exposures are rare. Moreover, along the coast there is often a more or less continuous covering of sand which tends to obscure the clay deposits.

*Exploitation.*—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 evidence. Borings made with an auger furnish a more satisfactory and rapid means of determining the thickness of the clay deposit away from the outcrop.

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 are made.

*Winning the clay.*—Having determined the thickness, extent and character of the clay, there still remains several important points which have to be considered.

One of these is the amount of stripping. Unless the clay is 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 sand, there is in some localities a market for it 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 stream of wet sand, which should not be penetrated.

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 haulage with teams is 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 MINING.**—The methods of mining employed are slightly different for clays and shales, the latter on account of their greater hardness requiring stronger machinery. All that follows below regarding mining methods will apply to clay.

1. *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; but in case no outcrop is accessible, it is necessary to sink a vertical shaft 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 as follows:

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. Where the clay is not interstratified 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.

No underground mining for clay is done in the Virginia Coastal Plain area nor would it be practicable.

*Surface working.*—This consists in digging the material from open pits or cuts of variable size. Where the pit is small, it is commonly the custom to use picks and shovels to dig the clay (Pl. XI, Fig. 2.); and, indeed, this method is necessary in those cases where the clay is not of uniform quality from top to bottom, or when the bank contains a number of layers of different kinds. It is then necessary to strip off each one separately and place it in a separate storage pile or bin.

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. 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 a 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.

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.

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 be built in the pit, halfway up its side, or else the clay is loaded into buckets and hoisted to the surface by means of a derrick operated by steam- or horse-power.

When the clay lies above the ground or road level, there is less trouble with the 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.

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 excavation 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. 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.

When clay deposits are worked as a bank or large pit, the clay is commonly dug by means of pick and shovel, but if the scale of operations warrants, a steam shovel is far better and more economical. If the clay is tough, the material is sometimes loosened by

means of a blast, but more often by undermining or falling. This is done by digging a narrow cut into the bank at its base, and then driving in a line of wedges on top, one or two feet from the edge. In this manner large masses weighing many tons are pried off and break in falling.

Steam shovels are much used in some of the clay pits around Alexandria, where a large area has been worked over.

*Pit mining for kaolin.*—Some clays, like kaolin, occur in vein-like deposits, which are narrow as compared with their length, and have to be mined by special methods. In these a circular pit of about 25 ft. diameter is dug, and sunk to the bottom of the clay. The sides of the pit are supported by a crib work of short timbers which are anchored every four feet. When the clay has been dug out the pit is filled in, and a new one started next to it. The old pit is filled, if possible, by stripping removed in digging the new one. Such pits are sometimes dug to a depth of over 100 feet.

**PREPARATION OF CLAY AFTER MINING.**—For most grades of clay products, the clay is run from the bank directly to the machine, but where used for the better grades of clay ware, some preparation is oftentimes necessary.

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 a shaft revolves, bearing a series of arms or stirrers. The clay, after soaking a short time in a pit, is shoveled into the washer, into which a stream of water is also directed, 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 into which the material is discharged is constructed of plank 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 1,000 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 much very 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 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 are of wood, usually about 4 feet deep, 8 feet wide and 20 to 50 feet long. As soon as one is filled, the water and clay is 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. 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. It commonly takes about two hours to fill a press. 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.

In Virginia the washing of clays is practised only at kaolin mines.

## CHAPTER IV.

## THE MANUFACTURE OF CLAY PRODUCTS.

## INTRODUCTION.

Although many persons are familiar with the wide distribution of clay, yet few appreciate its value or the wide variety of uses to which it is put. All recognize its application to brick manufacture, and table or toilet ware, but here the knowledge of its value often ceases. Even the lower grades of clay have a wide variety of uses.

**USES OF CLAY.**—Since the owners of clay property are often desirous of knowing to what uses clays can be put, the following table is given:\*

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

*Structural.*—Brick; common, front, pressed, ornamental, hollow, glazed, adobe; terra cotta; roofing tile; glazed and encaustic tile; drain tile; paving brick; chimney flues; chimney posts; door knobs; fire proofing; terra-cotta lumber; copings; fence posts.

*Hygienic.*—Urinals; closet bowls; sinks; wash-tubs; bath-tubs; pitchers; sewer pipe; ventilating flues; foundation blocks; vitrified bricks.

*Decorative.*—Ornamental pottery; terra cotta; majolica garden furniture; tombstones.

*Minor uses.*—Food adulterants; 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.

*Refractory wares.*—Crucibles and other assaying apparatus; gas retorts; fire bricks; glass pots; blocks for tank furnaces; saggers; stove and furnace bricks; blocks for fire boxes; tuyeres; cupola bricks; mold linings for steel castings.

---

\* Hill, Mineral Resources, U. S. Geological Survey, 1891, p. 475.

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

**CLASSIFICATION OF CLAYS.**—The classification of clays may be based on their uses, origin, or physical and chemical properties; any of which are more or less unsatisfactory. Certain variety names are often used, which are more indicative of the physical characteristics of the clay than its application. Many of these are given below.

*Kaolin.*—A term applied to white-burning residual clays, used in the manufacture of white earthenware, porcelain, wall tiles, white floor tiles, paper making, etc. White burning sedimentary clays are referred to by a few as plastic kaolins.

*Ball clays.*—White-burning, plastic, sedimentary clays, employed chiefly in the manufacture of the finer grades of pottery, namely, those having a white body.

*Fire clays.*—A term loosely applied to clays considered suitable for making fire brick. No standard of refractoriness has been adopted in this country, and many clays are called fire clays which have absolutely no right to the name. A classification of fire clays is suggested by the writer under fusibility.

*Stoneware clays.*—Under this term are included such clays as are adapted to the manufacture of stoneware. They must show good plasticity, dense-burning qualities and good tensile strength. The lower grades of stoneware are often made from a non-refractory clay, but the better grades are generally made from a No. 2 fire clay.

*Sagger clays.*—This is a term applied to clays which are used for making saggars, in which white ware and other high grades of pottery or tiles are burned. The clays employed vary in their character; they must be of sufficient refractoriness to hold their shape at the temperature at which they are burned. None of those seen in the Coastal Plain are adapted to this purpose.

*Terra cotta clay.*—This term does not mean very much and is used rather indiscriminately to indicate different kinds of clays, which are being dug for the manufacture of terra cotta. Most of the clays used for this purpose are semi-refractory, and buff-burning, sometimes sandy, at other times dense burning. Red-burning

clays are but little used now in terra-cotta bodies, and the Coastal Plain clays so far as known are not well adapted to this purpose.

*Retort clay.*—A dense-burning, plastic, semi-refractory clay, used chiefly in the manufacture of stoneware.

*Pipe clay.*—This term is a loose one, applied to almost any fine-grained plastic clay. Strictly speaking, it would refer to a clay used for sewer pipe.

*Brick clay.*—This includes all impure, non-refractory clays adapted to the manufacture of common brick. The less sandy kinds are often used for drain tile.

*Paper clay* includes many white, fine-grained clays, which are used for filling paper.

*Paving brick clay.*—This includes both clays and shales of red burning character, and of such a composition and texture that they can be vitrified.

#### THE METHODS OF MANUFACTURE.

In the present report are considered only the manufacture of those products which could probably be made from clays occurring within the Coastal Plain area of Virginia. This, therefore, includes common and pressed brick, paving brick, drain tile, roofing tile, fire proofing, low grade fire brick, red earthenware, and stoneware. From this it will be seen that such products as terra cotta, sewer pipes, floor and wall tiles, white earthenware and porcelain are omitted.

#### THE MANUFACTURE OF BUILDING BRICK.

Building brick include common, face, and pressed brick, enamel brick and glazed brick. A consideration of the last two is excluded from this report. Common brick include all those used for ordinary structural work, and are employed commonly 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 often used for front walls. They are usually made without much regard to color, smoothness of surface, or sharpness of edges.

Face, front, or pressed brick, includes 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.

## RAW MATERIALS.

*Clays for common brick.*—The clays used for common brick are usually of a low grade, that is they contain a large amount of impurities, and are often gritty. Except in certain districts, those selected are almost invariably 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. Few brick clays are used as taken from the bank, but they are generally mixed with sand. In fact so much sand is sometimes added that the air shrinkage is not more than 2 or 3 per cent. Moreover, in burning, the temperature oftentimes does not exceed the fusion point of cone 012 or 011, so that the fire shrinkage is exceedingly low, and the firing not always intense enough to give a good hard brick.

Of course in some cases it is necessary to mix in some sand or sandy clay, as otherwise the mixture would be too tough to mold easily, and shrink too much in drying and burning. The blue bottom clay from Suffolk is a good example of a material which requires the addition of a less strong clay or sand. Some clays, however, are so tough, that it is difficult to thoroughly incorporate the materials added, without proper mechanical separation.

Common brick clays vary widely in their composition. Taking the analyses of all those dug and used for this purpose in the Virginia Coastal Plain we get the following figures:

## CHEMICAL COMPOSITION OF SOME VIRGINIA COASTAL PLAIN BRICK CLAYS.

Constituents	Minimum	Maximum	Average
Silica (SiO <sub>2</sub> ) .....	51.12	85.72	68.74
Alumina (Al <sub>2</sub> O <sub>3</sub> ) .....	5.83	28.97	16.62
Ferric oxide (Fe <sub>2</sub> O <sub>3</sub> ) .....	1.74	10.70	5.33
Lime (CaO) .....	.10	1.46	.45
Magnesia (MgO) .....	.05	1.18	.38
Potash (K <sub>2</sub> O) .....	.75	3.13	2.05
Soda (Na <sub>2</sub> O) .....	.22	1.23	.72
Titanic oxide (TiO <sub>2</sub> ) .....	.00	1.95	.44
Water (H <sub>2</sub> O) .....	2.81	8.63	5.18

The average composition of several hundred analyses from all parts of the country is as follows:\*

\* H. Ries, Bull. N. Y. State Museum, No. 35, pp. 639, 189.

Silica ( $\text{SiO}_2$ ).....	49.27
Alumina ( $\text{Al}_2\text{O}_3$ ).....	22.774
Ferric oxide ( $\text{Fe}_2\text{O}_3$ ).....	5.311
Lime ( $\text{CaO}$ ).....	1.513
Magnesia ( $\text{MgO}$ ).....	1.052
Alkalies ( $\text{Na}_2\text{O}, \text{K}_2\text{O}$ ).....	2.768
Water ( $\text{H}_2\text{O}$ ).....	5.749
Moisture.....	2.502

Clays suitable for common brick are found in many parts of the Virginia Coastal Plain area, and are worked at a number of points as described in chapter V.

*Pressed brick.*—These require a higher grade of clay than is necessary for common brick. At the present day those most used are buff-burning clays, of a semi-refractory character. In addition to these, red-burning clays and white-burning clays are also employed. The third class does not occur in the Virginia Coastal Plain, so far as known. Red-burning clays are by no means uncommon, and some of those now utilized for common brick could be applied to the manufacture of pressed ones. Buff-burning clays are rare; certain beds around Alexandria give a buffish product, and some of the Pleistocene clays on the lower Rappahannock river also burn buff, but the former of these only are used for face brick.

The physical requirements of a clay for pressed brick are: (1) uniformity of color in burning; (2) freedom from warping or splitting; (3) absence of soluble salts; (4) sufficient hardness and low absorption when burned at a moderate temperature. The air and fine shrinkage, as well as tensile strength, vary within the same limits as for common brick.

At the present day, buff-burning, semi-refractory or refractory clays are probably more used than any others. This is partly because their color finds favor, and partly because coloring material 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. Of these, manganese is the most important, and is obtainable in many localities in Virginia.

The clay must necessarily burn hard at a moderate temperature, and in the case of red-burning clays the temperature reached is usually the fusing point of cone 1 or 2. Many of the Pleistocene clays in the Coastal Plain yield an excellent hard product at this temperature. If buff-burning clays are employed it is commonly necessary to go to cone 7 or 8 to make the brick steel-hard.

A chemical analysis is of little use in judging the value of a clay for pressed-brick manufacture. It is true that the ferric oxide content will give us a clue to the color burning qualities of the clay, and a high silica content would indicate high absorption and low shrinkage, but that is all; so that a physical examination of the material is imperative.

#### METHODS OF MANUFACTURE.

The methods employed for making common and pressed brick are often very similar, the differences lying chiefly in the selection of the 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.**—Many clays are put through a preliminary treatment before being mixed with water or tempered, and while clays for either pressed or common brick may go through this treatment, more care is naturally given to the preparation of clays for common brick than those for pressed brick.

*Weathering.*—This is a natural process of preparation. By spreading the dug clay out and leaving it exposed to the elements, it slakes down under the action of rain, and is more or less broken up by the frost. The whole mass thereby becomes more or less thoroughly disintegrated and homogenized. Iron nodules, if present, rust out, 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. The number of establishments where clays are weathered is few, and it is almost never practiced in the case of common clays. One yard at Suffolk digs its clay and leaves it exposed through the winter. Weathering clay sometimes makes up for insufficient tempering, but this should not be relied on to prepare the clay in all cases.

*Dry crushing.*—When hard material like shale is used, it has to go through some form of crushing machine, which will comminute it sufficiently to permit its mixing with water. The same thing has to be done if the clay is to be worked in a dry press machine, and in this case the material has to be ground, whether shale or clay.

Several types of crushing machines are used, the selection of which depends on the character of the raw material, degree of fineness required, capacity, and perhaps in some cases personal preference. The more important types used are jaw crushers, rotary crushers, rolls, and disintegrators.

*Crushers.*—The jaw crushers consist of two movable jaws that interact, and are set closer together at their lower than at their upper ends. One jaw is stationary, the other is pivoted at its lower end. The material to be crushed is fed into the opening between the top of the jaws and moves slowly downward, until it is fine enough to pass out between the lower edges of these.

In the rotary crushers, the machine consists essentially of a cylindrical hopper, within which there rotates a conical metal head, whose surface is corrugated, and which revolves with a gyrating motion. Of these two types of crusher, the former is more often used, and requires less power, but the latter is adapted to a wider range of material, because it is adjustable. The capacity of these crushers varies from two to two hundred tons per hour, according to the character of the shale.\*

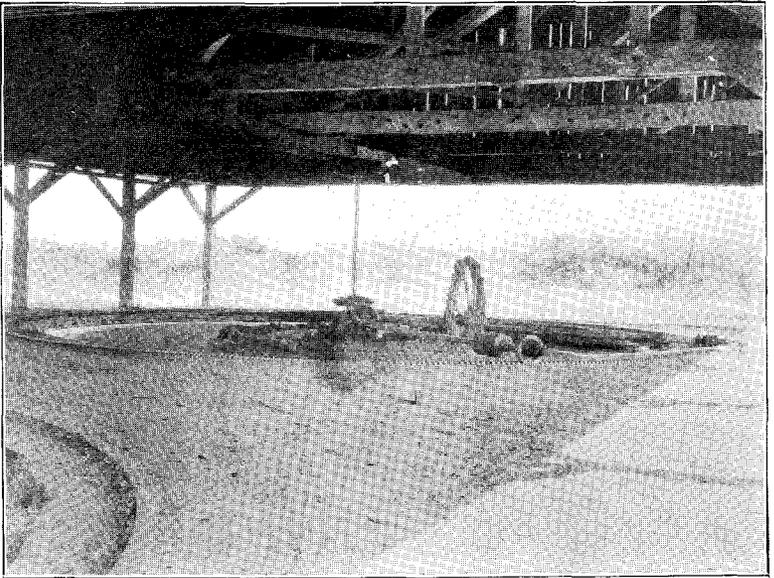
It should be remembered that these materials are applicable only to dry materials, and not wet ones.

*Rolls* consist of two steel cylinders, revolving at different velocities. The rolls are often adjustable, so that they can be set at varying distances apart, according to the size to which the clay is to be crushed. The differential speed of the two rolls serves not only to pull the material in between them, but also exerts a tearing action of the lumps. The surface of the rolls is either smooth-toothed or corrugated. The surface of some rolls is provided with a spiral thread, which catches large stones and carries them to the edge of the rolls where they are thrown out. Smooth conical rolls act in the same manner and are not infrequently used for preparing stony clays. In many cases the use of rolls for soft, wet clays, does not seem to prepare them very well, as the rolls simply flatten the lumps. An average size roll will prepare sufficient clay for 25,000 to 150,000 bricks per day, depending on the size of the rolls and their speed.†

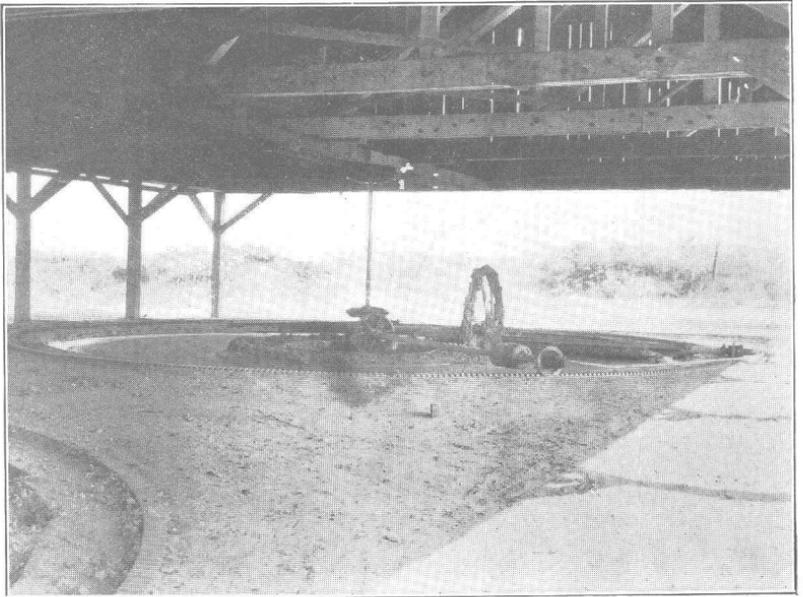
---

\* Williams, Iowa Geological Survey, Vol. XIV, p. 165.

† Iowa Geol. Survey, Vol. XIV, p. 168.



Ring pit used for tempering clay.



Ring pit used for tempering clay.

*Disintegrators* represent a third type of machine used for breaking up clay and shale, and, where used, are commonly found to be quite effective, provided they are run on dry material. Their capacity is large, but much power is also required to drive them. A disintegrator has several drums or knives on axles, revolving rapidly within a case and in opposite directions. As the lumps of clay or shale 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. Such machines can pulverize from 8,000 to 28,000 pounds of material, such as shale, in one hour, and are said to require from two and one-half to four-horse power per ton per hour. Since disintegrators work best on dry material, they are commonly used in the dry-process of brick manufacture.

*Dry pans* are much used for hard clays or soft shales, but they are also adapted to a wide range of materials. They consist of a circular pan in which revolve two large mullers, supported on a horizontal shaft, which may be in one piece or in two, in which case the mullers revolve independently of each other. The wheels turn because of the friction against the bottom of the pan, the latter being rotated by steam-power, and, in turning, grind by reason of their weight, which is from 2,000 to 5,000 pounds. The machine is constructed so that the mullers have some vertical play, thus permitting them to run over any lump which may not be hard enough to crush. The bottom of the pan is made of perforated removable plates, so that the material falls through as soon as it is ground fine enough, and two scrapers are placed in front of the rollers to throw the material in their path. The diameter of a dry pan ranges from 6 to 9 feet. Dry pans form a highly efficient machine, even though they are wasteful of power. Their capacity depends on the size of the screen meshes, and character of the raw material, whether hard or soft, dry or moist. For a medium shale it is possible to grind 8 tons per hour through a 1-8 inch screen, and about 12 tons through a 1-4 inch screen. Few rolls are used in the Virginia Coastal Plain area.

*Ball Mills*.—These form a type of machine especially adapted to fine grinding. They consist of a tube closed at both ends, and revolved by means of a suitable gearing. The charge which partly fills the tubes consists of rolled flints, and the clay to be

ground. Ball mills are not adapted to anything but high-grade clays and hence they are not discussed further here.

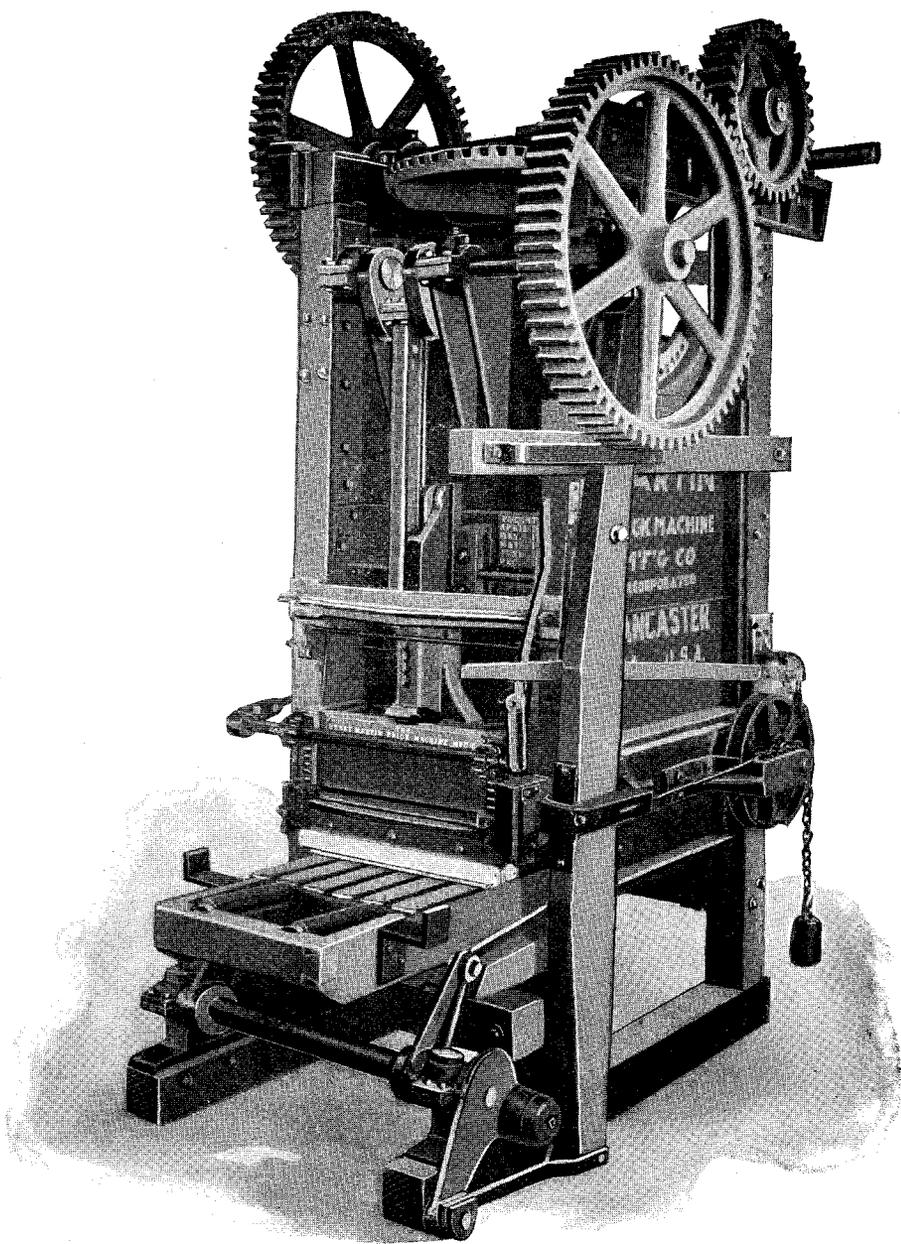
*Machines for preparing wet clay.*—These include soak pits, ring pits, pugmills and wet pans.

*Soak pits and ring pits* represent a primitive form of machine, much used at common brick yards. The former are semi-circular or rectangular pits in which the clay and water are allowed to soak over night, while the latter consists of a shallow circular pit in which the clay and water are mixed by a large iron wheel traveling around on a horizontal axis. (Pl. III.) The use of both is being slowly but surely discontinued to make room for the next type.

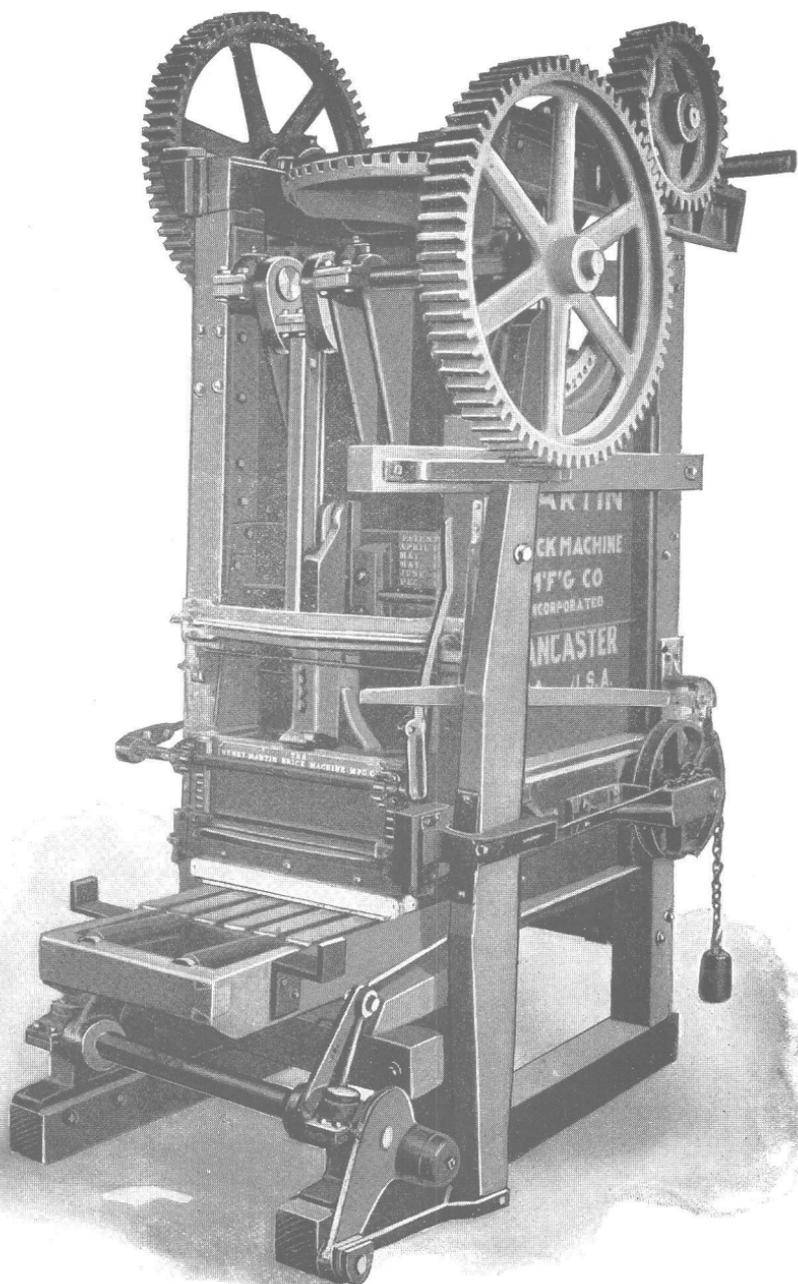
*Pugmills.*—These consist usually of semi-cylindrical troughs varying in length from 3 to 14 feet, with about 6 feet as an average. In this trough there revolves a horizontal shaft, bearing knives set spirally around it and having a variable pitch. The clay and water are changed at one end, and the blades on the shaft not only cut up the clay lumps but mix the mass, at the same time pushing it towards the discharge end. The speed of the clay through the machine varies with the angle of the blades on the shaft. Theoretically, the entire mass of clay will be mixed up by the revolving blades, but if the machine is overcharged it is not uncommon to see lumps of clay travel from one end of the trough to the other, before they are pushed through the discharge end. This can be obviated by using a closed form of pugmill, in which the clay is under pressure and the mixing action of the machine becomes more effective. The thoroughness of the mixing depends partly on the clay and partly on the length of the mill. Short ones on account of their cheapness appeal to some manufacturers, but their use should be avoided, especially in the Coastal Plain region, where the common clays used are so often of a mottled character, that it requires thorough pugging to homogenize them.

Pugmills are thorough and continuous in their action, take up less space than ring pits and do not require as much power to operate them. With a good working clay, a pugmill will, in ten hours, temper enough clay for 25,000 to 60,000 brick according to its size. They are in operation at but few yards in the Coastal Plain belt, and their use should be extended.

*Wet pans* represent one of the most efficient machines for preparation that the brick-maker can select, since they do both grinding



Cut of a soft-mud brick machine



Cut of a soft-mud brick machine

and mixing in the same operation. Structurally, they 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 at the same time mixed with the water. Where the clay contains hard lumps of limonite, or pyrite nodules, a wet pan is superior to a pugmill, as these are crushed. It takes but a few minutes to temper a charge, which is then removed by a shovel, mounted on a pivoted-bearing by the side of the pan. A new charge is then added. It will be seen, therefore, that a wet pan is not continuous in its action, and its capacity is consequently smaller than that of a dry pan of corresponding size, although the amount of power required to operate it will be the same. The wet pan is not used in common brick manufacture, nor, as a rule, for those clays which are free from stones.

*Screens.*—When clay or shale is crushed dry, it is customary to screen it for the purpose of separating all particles that are too large and returning them to the crusher.

There are a number of different makes of screens on the market, but all belong to one of three types, namely, the inclined stationary, the inclined bumping screen, and the rotary screen of either cylindrical or polygonal section. Their qualities may perhaps be briefly summed up as follows:

Fixed inclined screens are cheap, and require few repairs, but they take up more space, are of low capacity, and, on account of their inclined position, require the material to be hoisted to their upper end so that it can be discharged on them.

Shaking screens are very efficient, and keep themselves pretty clean, so that the clay does not clog. On account of their jarring motion, however, there is more or less wear on the screen itself as well as on the building.

Rotary screens are of large capacity, especially if of polygonal section, and provided there is some means for keeping the screen cloth clean.

Screens are used in connection with the dry-press process.

*MOLDING.*—Bricks are molded by one of the three methods, namely, soft-mud, stiff-mud, and dry-press.

*Soft-mud process.*—In this method the clay is mixed to the consistency of a soft-mud and pressed into wooden molds. This originally was done by hand, and this indeed is the method still

followed at many small yards. The more modern method however consists in forming the bricks in machines driven by steam-power.

Since the clay mixture is sticky when wet, 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, while the sixth surface will be somewhat rough, due to the excess of clay being wiped off even with the top of the mold. They are also slightly convex on one side and slightly concave on the other, caused by the sides of the soft brick dragging slightly as it is dumped from the mold, to the drying floor.

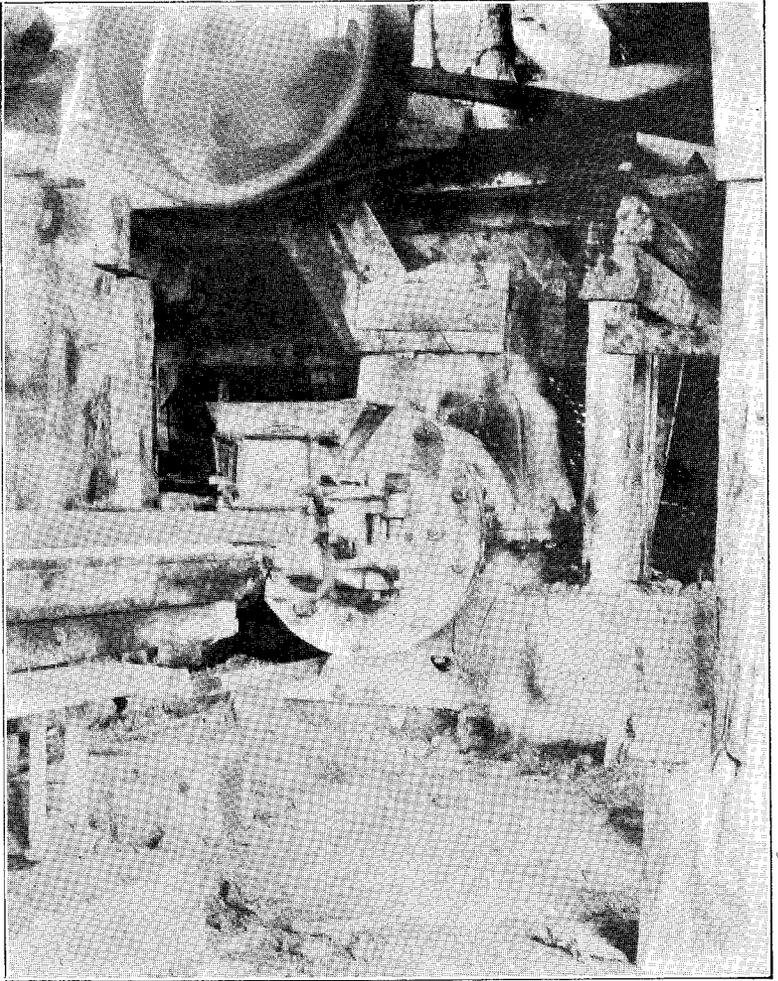
The soft-mud machine (Pl. IV.) consists usually of an upright box of wood or iron in which there revolves a vertical shaft, bearing several blades or arms. Attached to the bottom of the shaft is a curved arm, which forces the clay into the press box. The six compartment molds after being sanded either by hand or in a sanding machine, are shoved underneath the press box from the rear side of the machine. The plunger descends in the press box and forces the clay into the mold, after which the latter is pushed forward automatically upon the delivery table, while an empty one moves into its place. The upper surface, of the mold is then "struck" off by means of an iron scraper. Under very favorable conditions soft-mud machines have a capacity of about 40,000 bricks per ten hours, but most of them rarely exceed 25,000.

The soft-mud process is adapted to a wide range of clays, and produces a brick of very homogeneous structure, which is rarely disintegrated by frost. Since the pressure applied to the brick is not as great as that given to it in other methods of molding, the product is somewhat porous. This, however, tends toward the development of brighter colors, since the iron in the clay is more easily oxidized during burning.

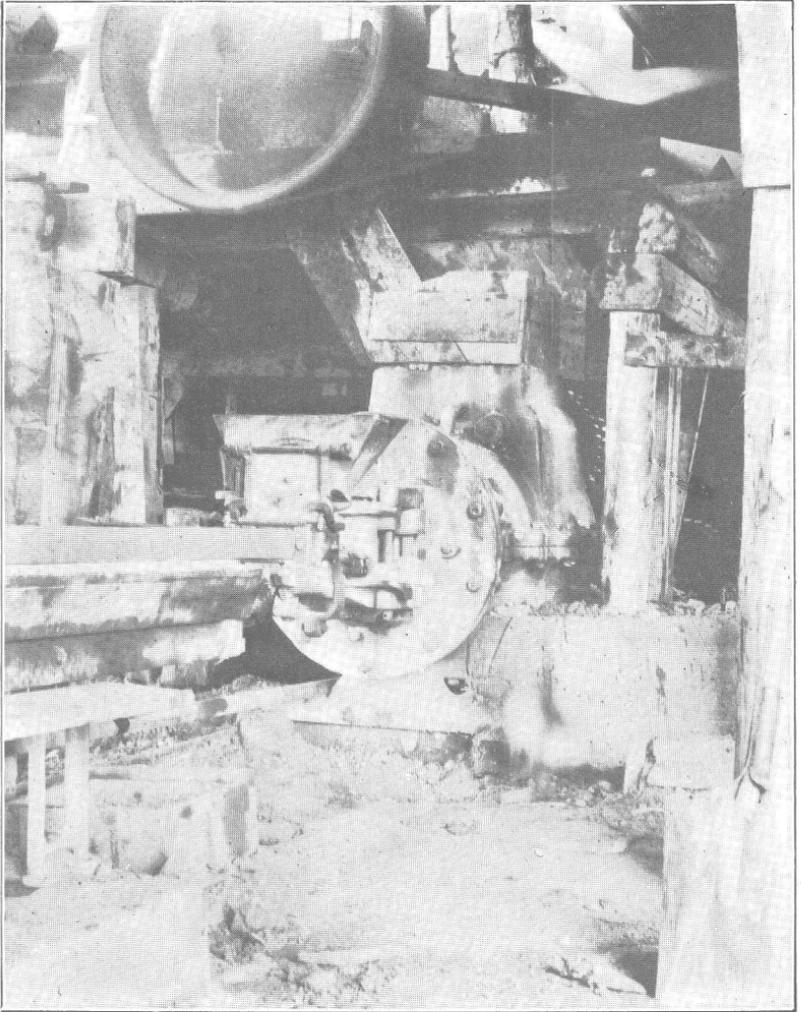
The cost of the soft-mud process is small, but its capacity is limited as compared with a good stiff-mud machine, and for the same capacity a larger number of men are required to operate it.

The soft-mud machine does not produce a product with smooth faces or sharp edges, but this defect can be overcome by repressing the product, and where the bricks are to be used for fronts this is often necessary.

Curiously enough many of the Coastal Plain yards of Virginia still adhere to the hand method of molding.



A stiff-mud brick machine; shows bar of clay issuing from die.



A stiff-mud brick machine; shows bar of clay issuing from die.

*Stiff-mud process.*—In this method of molding the clay is tempered with less water, and is consequently much stiffer. The principle of the process consists in taking the clay thus prepared and forcing it through a rectangular die in the form of a bar which is then cut up into bricks. The machine now most used is known as the auger type. (Pls. V, VI, and VII.) This consists of either a vertical or horizontal (usually the latter) pugging chamber from which the clay passes to the die, and is forced out through the latter by means of an auger. The internal shape of the die is variable, depending on the make of the machine, and 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 moved forward until it is seized by the auger and forced through the die. Since this involves considerable power it results in a marked compression of the clay. One serious fault of the stiff-mud machine is its tendency to produce a laminated structure in the bar of clay. This is due partly to the action of the auger, which acts to twist the clay into a series of concentric layers, that slip over each other producing a slickened surface. This laminated structure is still further emphasized by the friction between the sides of the die and the surface of the clay bar, which causes its central portion to move faster than the outer part.

The laminated structure is greatest in highly plastic clays, but with proper pugging and lubricating it can be often decreased, and machine manufacturers have spent much time endeavoring to perfect a die and auger which will give smooth results. Lubrication of the die also serves the purpose of preventing serrations on the edges of the bar. Neither very sandy nor highly plastic clays yield good results in an auger machine.

Laminations are undesirable, as they weaken the brick, but are more harmful in pavers than in common building brick; their effect is probably lessened by harder burning.

Some machines are provided with a sand box, which sands the bar of clay as it issues from the die, the object of the sand being to prevent the bricks sticking together in burning, or improve their color, and incidentally to aid in handling. The brick made in auger machines are either end cut or side cut, depending on

whether the area of the cross-section of the bar of clay corresponds to the end or side of a brick.

The auger machine has a large capacity, and can produce 45,000 or even 60,000 bricks in ten hours, the output of the machine being sometimes increased by the use of a double or even triple die, but this is not a desirable practice. A machine making eight to ten thousand brick per hour requires seventy to seventy-five horsepower.\*

As the bar of clay comes from the machine it passes on to the cutting table, of which there are several different types, the cutting apparatus being operated either by hand or automatically, but the cutting is in every case done by wires, which are drawn across the bar. These wires have to be as thin as possible and yet be strong; they must make a small clean cut in a downward direction. Strong and thin as they are they nevertheless are easily broken by striking on stones, roots or hard lumps, within the bar of clay. In some cutters the wires are fastened with springs so that there may be some give to them in case they meet with an obstruction in cutting the clay. Some cutters are also provided with automatic wire cleaners.

Cutting machines are of two classes, namely, those in which the cutting wires move at right angles to the bar, and those in which the wires revolve in the same direction in which the clay moves.

Those of the former type are so designed that the wires are drawn either straight through it from one side to the other, or else they cut through it with a partially rotary motion. A cutter of this type may be operated by hand or automatically. In the latter type, there are a number of short wires, each borne on a fork-like frame at the end of a series of arms corresponding to the spokes of a wheel. This cutter revolves as the bar of clay issues from the die, so that each wire as it descends cuts through the bar.

Any of the several types of cutting machines mentioned can be used for either end-cut or side-cut bricks, and although there are many different makes of cutting tables on the market it is doubtful whether any possess special advantages over the others.

The stiff-mud process is adapted mainly to clays of moderate plasticity, and does not work well with stony clays, unless the stones

---

\* Iowa Geol Survey, Vol. XIV, p. 195.

are previously removed, for the cutting wires are likely to be broken by contact with them, which necessitates a frequent stoppage of the machine for repairs. While these do not take long to make, still delays of any kind are expensive. Stiff-mud brick, like soft-mud ones, can be repressed, and many face brick are now made by this method.

The stiff-mud process is a good one, if properly used, but the clays should be thoroughly tempered before molding.

*Repressing.*—Many soft-mud and stiff-mud brick, that are to be used for fronts or pavers, are repressed for the purpose of giving them greater density, straightening the edges and smoothing the surfaces. The repressing of stiff-mud brick can be done as soon as they are molded, or after they have been hacked for several hours. Soft-mud brick have to be dried somewhat before being sent to the repress.

The repress consists essentially of a steel mold box, into which the molded brick is dropped automatically and pressure applied from above or below or both, by means of plungers. The pressure is applied gradually until it reaches its maximum, or else the brick may be given two distinct pressures, with a slight interval of relief between. The latter probably yields the best results. The amount of pressure varies, and in the strongest machines a maximum of 45,000 pounds per square inch can be attained,\* but the amount of pressure given to the brick can be regulated.

Since the brick does not fit perfectly into the mold, it will undergo a slight change of dimensions in repressing, which involves increase in length and width and decrease in thickness; the cubic volume will, however, be less after repressing than before. A certain amount of flow thus takes place in the mass, resulting naturally in something of a change in structure. There has been much discussion regarding the advantages of repressing, and the possibly injurious effects.

If a brick fits tightly into the press box of the repress, practically no change of structure takes place in repressing; if there is some room for a flow of the mass the original structure may be partly destroyed; or, if the brick fits loosely, the flow in the mass may be sufficient to produce an entirely new structure.

---

\* Iowa Geol. Survey, Vol. XIV, p. 204.

Since the action of most represses agree most nearly to the second of the three cases mentioned, it would seem doubtful whether repressing could be looked upon as desirable treatment.

Some years ago the National Brick Manufacturers Association appointed a committee to investigate this subject and determine, if possible, whether repressing always increased the strength of a brick. After making a long series of experiments on both end cut and side cut brick, they found that in most cases, repressing injures the wearing qualities of the brick. Following this was a series of experiments to determine the influence of flow in the repress die, in which they used dies permitting a varying degree of flow in the mass during repressing. Their conclusions were, that it is best to assume that plain wire cut bricks are superior to repressed ones, until it can be proved that in any case the reverse holds true.

Repressing is at times necessary in order to meet local requirements, or market conditions, in which case it should be of such character as to completely destroy the auger machine structure, and develop an entirely new one. Under such conditions the brick may often be improved.

Repressed bricks often have a very smooth surface, caused in part by the rubbing of the clay against the sides of the die, and in part by the liberal use of oil, which tends to facilitate the delivery of the brick from the press box. The operation of repressing may also serve to form a skin which is denser than the interior of the brick and thus protect it against the weathering. If stiff-mud bricks are to be used for fronts it is often desirable to repress them because many irregularities of surface caused by the cutting wires are thus reduced.

*Dry-press process.*—In this method of molding, the clay is used in a nearly dry condition, that is it may contain perhaps 15 per cent. of moisture. The clay is first pulverized in some form of pulverizer or dry pan, screened to from 12 to 16 mesh, and then delivered to the machine. Before describing the latter, it may be well to refer to the methods of preparation used. If plastic clays are chosen these are often too moist when first dug and are stored up under a shed for the purpose of drying out as well as disintegrating them. Shales, too, are often stored up in piles in order to allow them to mellow somewhat. Disintegrators seem

often to pulverize the raw material more finely than a dry pan, and if the clay or shale is not ground fine enough, or not properly screened, it does not add to the appearance of the brick. Improper grinding yields coarse particles which give the brick a coarsely granular structure. Sandy clays do not always work well in a dry-press machine.

The molding machine consists of a steel frame of varying height and weight, with the delivery table about three 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 consists of a frame work which slides back and forth over the molds. It is filled on the backward stroke, and on its forward stroke allows the clay to fall into the mold box. As the charger recedes to be refilled, a plunger descends, pressing the clay into the mold.

The clay in most dry-press machines is subjected to several maximum pressures, the relief between pressures being for the purpose of allowing the air imprisoned in the clay by compression to escape through holes in the die. Were this not done, the expansion of the compressed air, following release of pressure, would burst the brick. After the clay has received its pressure in the mold, the upper plunger, and also the lower one (which forms the bottom of the mold box), ascend, until the molded bricks reach the level of the delivery table, when they are pushed forward by the charger as it advances to refill the molds. The mold is of hard steel and heated by steam to prevent adherence of the clay. The pressure necessary to form the clay is generally applied by means of a toggle joint, and four or six bricks are usually molded at a time according to the size of the machine. A four mold press will make about 20,000 bricks per day, and a six mold press about 30,000.

The advantages claimed for the dry-press process are, that in one operation it produces a brick with sharp edges and smooth faces. There is little water to be driven off, hence no drying apparatus is necessary. The process itself is probably the cheapest that there is for molding brick, although the initial cost of the plant is somewhat high. If properly burned the bricks are as strong and durable as those made by any other process.

The dry-press process is adapted to quite a wide range of clays, and although the plastic qualities of the clay do not play any

role, still the more plastic clays seem to cohere better when dry.

Practically all of the clays produced in the Coastal Plain region of Virginia could be used for the manufacture of dry press brick, and yet there is but one machine of this type in operation in the entire area.

DRYING.—The primary object of drying clays is to free them of water added during tempering, and also the water which they originally held in their pores, although the latter is expelled with difficulty.

This water is removed by exposing the bricks to an atmosphere of hot air. In natural drying this is supplied by the sun; in artificial drying, it is generated with some form of fuel. As the water in the clays is warmed it begins to evaporate, forming watery vapor, and unless this is removed from around the brick, and fresh, dry air allowed to take its place, drying is retarded. Consequently, the air in which the bricks are drying, should be in motion. In open-air drying the wind aids this; in chamber or tunnel drying, the hot air passing up the chimney draws in a fresh supply of drier air behind it. Now while lack of motion in the air surrounding drying brick may retard evaporation, so, too, an excess of air current may accelerate it and indeed to such an extent as to make the brick shrink too fast and consequently crack.

Or, if, on the other hand, the brick is heated too rapidly, the water within the pores may be converted into steam, which, in its efforts to escape, splits the ware.

Bricks made by either the soft-mud or stiff-mud process have to be freed of most of their moisture before they can be burned. This is done by drying them in, (1) open yards; (2) on covered yards; (3) on pallet racks; (4) in tunnel dryers; or, (5) on floors.

In the open yards the bricks are set on the ground and dried by the heat of the sun; the same is the case on covered yards which differ only from the former in having a sectional roof which can be lifted up in stormy weather and closed in rainy weather. With the pallet system the bricks are set on racks, protected by a roof, and while not exposed to the direct rays of the sun are dried by its warmth. All these methods are essentially open air methods, one or the other of which is usually employed at common brick yards. Indeed it is very improbable that any of these will ever

go entirely out of use, to make way for artificial dryers. While cheaply operated, they possess many disadvantages. They are dependent on the weather, and bricks cannot dry in wet, stormy weather, neither can this system of drying be operated in winter. Drying proceeds very irregularly, fast one day and slow the next, according to the meteorologic conditions. In windy weather many tender clays have to be carefully protected, to prevent rapid drying and cracking.

They also occupy considerable space. It is possible to construct the roofed yards, referred to above, with steam coils under the floors, and utilize exhaust heat from the engine, thus greatly increasing their efficiency.

Tunnel dryers represent a drying system much used in brick plants at the present day, and is probably the most economical means there is.

They consist essentially of a series of parallel tunnels of brick or wood, heated either by hot air passing through them, or by heat radiated from steam pipes on the surface of brick flues. The heat passes in at one end, and out through a stack at the other, which is the cooler. The cars containing the green brick are pushed in at the cooler end, slowly traverse the tunnel and emerge at the other, so that while in use the tunnel is filled with cars of brick. Each time a car is pushed in at the cool end one is drawn out at the other end.

The action of the tunnel dryer is somewhat as follows: The hot air which enters the tunnel is moderately dry, but as it comes in contact with the brick in its passage towards the stack, it becomes loaded with moisture from the brick, so that when it gets to the chimney it is very close to saturation. The bricks entering the stack end come at once in contact with a hot moist atmosphere, which tends to warm them up, but permits of little drying, for the water in them will not pass off into an atmosphere which is already saturated with it. Consequently, the bricks at first become warmed up. As they move slowly towards the less humid air of the middle section of the tunnel they begin to lose some of their moisture and shrink; finally, when they reach the hot end the shrinkage has ceased but most of the remaining moisture is driven from their pores.

All clays cannot be dried with equal rapidity; indeed, some have to be dried very slowly in order to prevent checking. This is accomplished partly by moving them very slowly through the dryer and partly by diminishing the air current in the end, at which the brick enter. The latter is accomplished in some dryers by carrying off the hot air before it reaches the end of the drying tunnel, thus decreasing the circulation of the air at the entrance end of the tunnel.

Drying tunnels are heated in several different ways. The one most commonly adopted is to heat the interior of the tunnel by radiation from steam coils, which are arranged along the sides, or bottom or both. The coils are supplied by either live or exhaust steam, the former by day, the latter by night, or sometimes in the daytime as well. Some persons advocate live steam, while others prefer the exhaust. It seems probable however that the latter is the more desirable from the standpoint of economy, since we are utilizing a waste product.

Steam heating, whatever kind of steam be used, is probably the most desirable method, since it is efficient; there is little risk from fire due to overheating, and, moreover, the heat can be easily distributed from the point at which it is generated.

A modification of this type consists in having the steam pipes outside the dryer in a chamber by themselves, and by means of a fan draw the air over them before conducting it to the dryer.

According to Richardson\* the advantages of this form of dryer are: 1. Less pipe required; 2. Greater economy of steam; 3. Better circulation in dryer and hence more rapid drying; 4. Convenience of making repairs to steam pipes; and 5. This system permits of the use of waste heat from cooling kilns without any change other than the adjusting of dampers.

In another type of dryer the heat is generated in a fireplace and conducted through brick flues which extend under the dryer floor, the heat being thus radiated through the flue walls. The gases pass from the flues into the same stack which draws the heated air from the dryer, and thus aid the draft in it. Such dryers are not adapted to tender clays, and while their cost of maintenance is low they are exceedingly wasteful of heat.†

---

\*Clay-Worker, XLIV, p. 342.

†Iowa Geol. Survey, Vol. XIV, p. 258.

In both the foregoing types the bricks are heated by radiation from hot surfaces. There are other kinds of dryers in which the hot air is conducted directly into the tunnel, and comes in contact with the bricks. This heated air may be supplied by fuel burned for the purpose, or else by the waste gases from the kilns. In the former there is danger of the ware becoming coated with soot or a scum unless the combustion of fuel supplying the heat is perfect. The scum owes its formation to sulphuric acid from the combustion gases settling on the moist hot brick in the dryer attacking some compounds, such as carbonate of lime, and converting them into sulphates which remain as a whitish coating on the surface of the ware. Fans are often used to aid the draft.

Dryers heated by waste gases from cooling kilns are not yet extensively used in this country, although they possess many excellent points. With this method the heat from the cooling kiln is carried through pipes into the dryer. Since this air is usually much hotter than desired it is necessary to mix some cold air with it. At the same time the air must not be allowed to cool down to its dew point, as it would deposit moisture on the bricks.

The advantages of this system are that a waste product is being used as a source of the heat, while among the disadvantages are the cost of piping the hot air, and the great care needed to maintain the hot air at a constant temperature.

Some large plants in the United States are using the process with excellent results.

There are other drying methods such as slatted floors heated by steam coils, and brick floors warmed by hot air flues beneath them, but they are not used in the drying of building brick, and hence are not mentioned here.

**BURNING.**—This stage of the process of manufacture is an important one, and although the clay may have passed safely through the preceding stages, much loss may occur at this very point. The imperfect bricks thus obtained may be due (1) to mistakes of the burner; (2) to the clay; (3) to the fuel; and (4) to the construction of the kiln. In burning, certain changes, partly physical and partly chemical, take place in all clays, as the result of which the brick is converted into a solid mass, which is hard and rock-like when cool. Other changes, due to the presence of certain ingredients or certain physical characteristics of the clay, occur in specific cases.

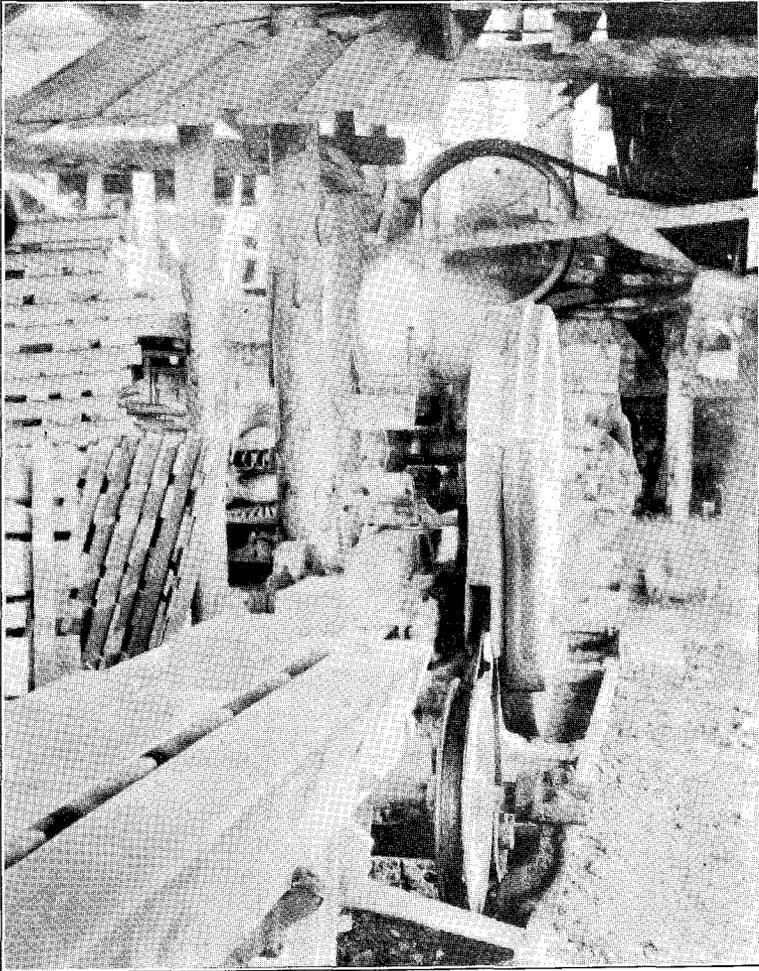
The amount of heat required for burning brick will vary with the clay; and the color, density and degree of hardness desired; the same clay giving different results, when burned at different temperatures. Common brick are rarely burned higher than cone 05 or 03, while pressed brick are frequently fired to cone 7 or 8, because the clays generally used have to be burned to that point to render them hard.

*General effects.*—In burning, the last traces of moisture are driven off. The chemically combined water is also expelled, most of it passing off at a very dull red heat. Its expulsion is shown by the steam (water smoke) issuing from the kiln and results in a slight loss of weight. If the bricks are set too wet, rapid heating causes much split or popped ware, due to the steam passing off too violently. This applies to mechanical and not chemical water. A good draft aids the evaporation of the water in the clay. A poor draft may cause moisture to condense on the surface of the ware and produce scumming.

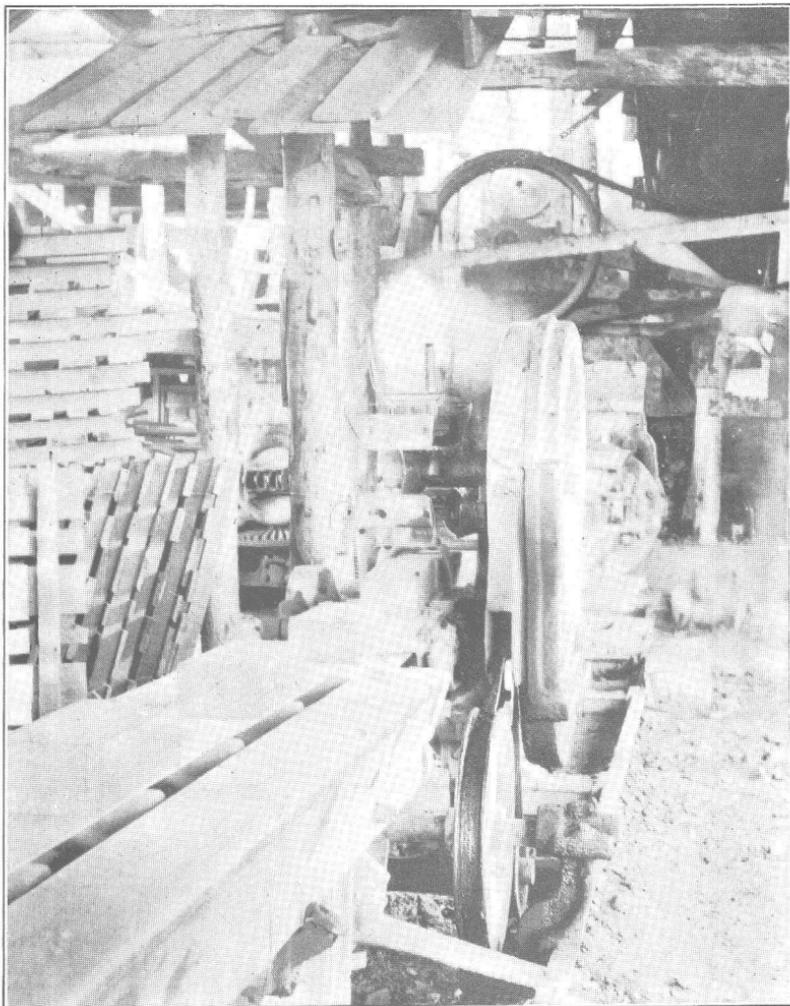
If the clay contains considerable carbonaceous matter, this will burn off at a low heat, provided in the first place sufficient air is present to insure an oxidizing atmosphere. In this case carbon in the clay uniting with the oxygen of the kiln atmosphere burns off as carbon dioxide. If the heat is raised too rapidly the clay contracts before all the carbonaceous matter is burned off, and the result is a black centre to the brick, which may also be accompanied by a swelling of the clay. In calcareous clays the carbonate of lime present also loses its carbon dioxide. The driving off of all these substances will, therefore, tend to make the brick very porous. Further heating, however, after volatilization of these substances, causes a drawing together of the clay particles, or shrinkage, and this is accompanied by an increase in density and hardness—the maximum density and shrinkage being reached when the brick is vitrified.

The effects of heating a clay may be summarized 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. A shrinkage of the mass by further heating.
3. Hardening of the clay due to fusion of some, at least, of the particles.



Cutting table of stiff-mud brick machine; shows revolving cutter, and the cut brick coming from cutting table.



Cutting table of stiff-mud brick machine; shows revolving cutter, and the cut brick coming from cutting table.

4. Increasing density with rising temperature, the maximum being reached at the vitrifying point of the clay.

*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 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 burns red, provided the iron is evenly distributed, unless much lime is also present. If only 2 to 3 per cent. are present, a buff product is obtained, whereas, with 1 per cent. or under, the clay burns white, or nearly so. 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.

When a clay is mottled a 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. Some Virginia clays contain lumps of bluish white 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 buff 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, because they have been drawn out by the evaporation of the water during the drying of the brick. (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 centre of the brick, not being thus affected by the gases, may show a buff color, whereas the outside has a different tint.

*Flashing.*—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 brick 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. Bleining's experiments showed that of three clays 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, fine grinding

seems to give more uniform flashing effects, and the reason that stiff-mud bricks 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 flash brick:

## ANALYSIS OF AN OHIO NO. 2 FIRE CLAY.

Silica ( $\text{SiO}_2$ ).....	67.14
Alumina ( $\text{Al}_2\text{O}_3$ ).....	19.74
Ferric oxide ( $\text{Fe}_2\text{O}_3$ ).....	2.46
Lime ( $\text{CaO}$ ).....	0.53
Magnesia ( $\text{MgO}$ ).....	0.71
Potash ( $\text{K}_2\text{O}$ ).....	2.80
Soda ( $\text{Na}_2\text{O}$ ).....	0.43
Water ( $\text{H}_2\text{O}$ ).....	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.

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 5 or 6 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  $\text{CO}_2$ ; 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 100 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  $700^\circ\text{C}$ ., the darker the flash under given conditions.

**KILNS.**—Bricks are burned in a variety of kilns, ranging from temporary structures, which are torn down after each lot of brick is burned, to patented or other permanent forms of complicated design. They are built on one or two principles, either up-draft or down-draft.

*Up-draft kilns.*—In these 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.

The simplest type of up-draft kiln is known as the scove-kiln, which is in use at many yards where common brick are made. With this method the bricks are set up in a large rectangular mass, from 36 to 42 courses high (in Virginia), while at the base a series of parallel arch-like openings is left extending through the pile. The bricks are surrounded by a wall two bricks thick, of green brick or underburned ones, and the exterior daubed over with wet clay to exclude cold air during burning. The top of the mass is closed by a layer of bricks laid flatwise, and termed the platting. The fuel is placed in the arches, and the heat ascends through the kiln and passes out at the top. Such kilns are adapted only to

the manufacture of common brick. They are wasteful of heat, difficult to regulate and require considerable skill. Moreover, the walls have to be torn down and rebuilt each time a new lot of bricks is burned. Then, too, the percentage of poor bricks is often large.

A step in advance of the scove-kiln is the up-draft kiln with permanent side, and partial end walls, and sometimes even a furnace for burning the fuel, instead of putting it in the arches. (Pl. VIII, Fig. 2.). It is this type of kiln which is most used in the Coastal Plain region. Such kilns can be better regulated, and there is less loss of heat and product. Another step further are those up-draft kilns, constructed with both walls, and roof permanent, the products of combustion escaping through a series of small chimneys at the top of the kiln. Such kilns are either rectangular or circular in plan.

*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. The down-draft system of burning is growing in favor, as the operation can be regulated better, and there is less loss from cracked or 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. There are many different types of down-draft kilns, most of which are patented, but they differ chiefly in the number and arrangement of the flues leading from the kiln chamber to the stacks, and in the shape and number of stacks as well. In the construction of such kilns it is essential to see that they are so built as to distribute the gases as evenly as possible throughout the kiln, otherwise irregular burning results.

If this is not looked after, the gases will, after entering the kiln chambers, attempt to take a short cut to the flues nearest to the stack. Where the kiln shows a tendency to act in this manner an effort is sometimes made to remedy it by setting the ware close in that portion which the gases follow too freely, so as to divert some of them at least into those parts of the kiln which do not receive enough heat. This tendency on the part of the gases to follow

the shortest route would be common in a circular kiln, with a center draft and one outside stack. The best results, and the most uniform heat are obtained by taking the gases off through a number of channels in the bottom of the kiln. The arrangement and size of these channels is variable, but the best results are obtained when with a central outlet, the flues nearest this are of smaller area than those farthest from it, the object of this being to counteract any tendency for the gases to follow the most direct path. But even if the kiln has a perfect draft, setting may to some extent interfere with this.

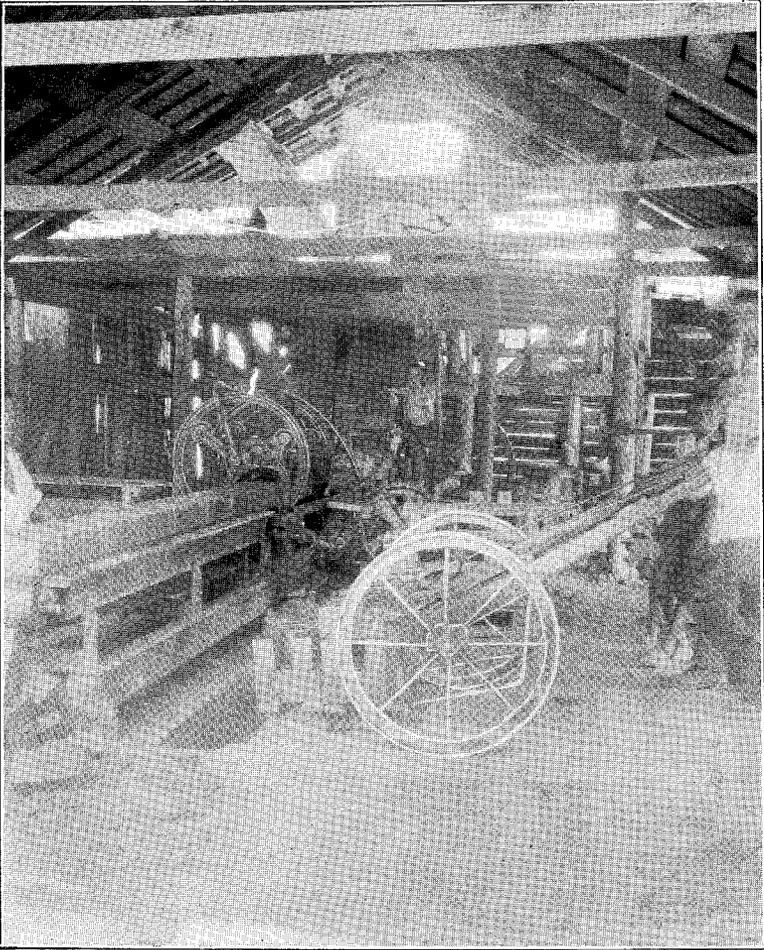
The bottom of a down-draft kiln is rarely as hot as the top, due partly to the gases cooling somewhat in their passage through the kiln. To overcome this, the draft may be accelerated, so as to draw the gases through the kiln as quickly as possible. A common means of accomplishing this is to have a false work or bottom of flues, under which there is a free space for the gases to move freely before entering the stack, the large volume of gas moving in this underspace tending to overcome the retardation caused by the gases passing through the set ware.

Down-draft kilns are either circular or rectangular in form, the former having a capacity of 25 to 60 thousand, and the latter from 150 to 200 thousand. The rectangular are more economical of space, and are the type commonly used for burning brick, while the circular ones are preferred for drain tile, sewer pipe, or stoneware.

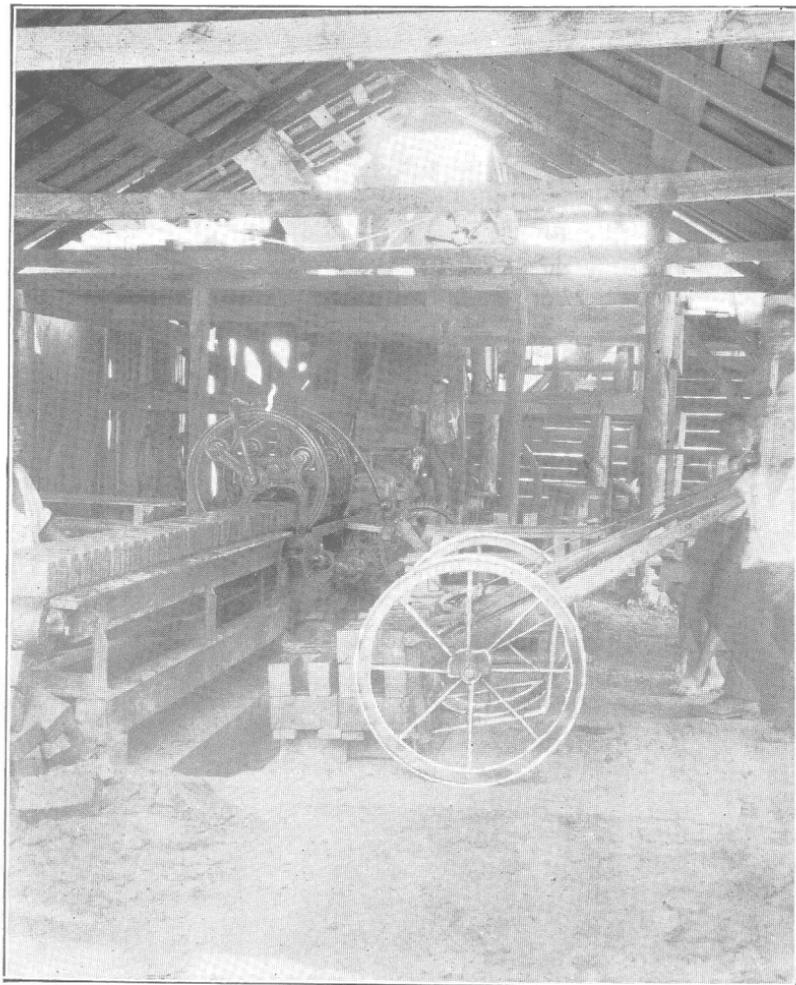
Rectangular down-draft kilns are often operated with one stack, located either at the end or side, the latter being preferable as it promotes a more uniform draft. In the circular kiln, a center stack gives the best results, even though it may take up some space in the interior of the kiln.

These kilns naturally require skill and intelligence to insure their proper workings, and must also be kept in proper repair, as well as having dry foundations to insure continuously good results.

In addition to finding considerable structural variation in the interior of the kiln, the style of fireplace or mode of firing varies. This may be done on flat grate bars, inclined grate bars, or dead bottom.



Stiff-mud brick machine and revolving cut-off for making side-cut brick.



Stiff-mud brick machine and revolving cut-off for making side-cut brick.

Of these, the flat or horizontal grate bar is the more often used, the fuel being placed on this and the air for combustion passing up through it. Firing by this method requires care, so as not to allow of too much air passing through the fuel, but the method permits higher efficiency. Overfeeding the fires results in smoke, and means loss of heating elements.

In some furnaces, styled coking furnaces, the grate has a plate of sheet iron or fire brick set in front of it, and on which the fresh fuel is placed before it goes into that portion of the fireplace where it is burned. In this position it gets preheated by the coal on the grates and is thereby warmed enough to drive off its volatile hydrocarbons, which are drawn in over the fire, where they are burned. If this same fuel were put directly on the fire, these gases would pass off in large part without being consumed. When the gases have been driven off, the coked coal is pushed onto the grate, where it is burned.

Inclined grate bars are set in a slanting position, reaching from the front of the furnace, part way towards the rear. In starting the fire, the fuel is heaped up at the rear of the furnace, and as coal is added the fire gradually builds up on the grate bars. The air for combustion passes in over the fuel and through it. There is less danger of an inrush of cold air into the kiln by this method of firing, but danger from gases passing into the kiln during cooling, for the fuel on the grates burns for some time after the firing is stopped. If the coal contains much sulphur this is liable to cause discoloration of the ware.

Dead-bottom firing is done without the use of grate bars, but the furnace is somewhat differently constructed, having an upper and lower opening in front. The fire is started in the lower part of the furnace or ash pit, and fuel gradually added, so that the mass reaches to the upper door, the top of the fuel being inclined. Owing to the necessity for cleaning out the fires from time to time, the supply of air is irregular, or, in other words, may alternate between reducing and oxidizing conditions. This is not favorable to the development of uniformity of color in the ware. This method is, however, a cheap one, and adapted to any grade of coal of the proper clinkering qualities.

*Continuous kilns.*—These were originally designed to utilize the waste heat from burning, and although the kiln has been con-

structed in several different forms, the principle of them all is the same. The kiln consists of a series of chambers, arranged in a line, circle, oval or rectangle, and connected with each other and with a central stack by means of flues. The object of this is to utilize the waste heat from the cooling ware, by drawing it through chambers of cooling ware, which are thus warmed by heat that would otherwise go to waste.

The chambers are separated by brick walls or temporary walls of thick paper, and each chamber holds about 20,000 brick. In starting the kiln, a chamber full of bricks is first fired by means of exterior fire boxes, and while the water smoke 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 covered by iron caps.

As soon as one chamber has reached its highest temperature, the two or three chambers 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. The distance ahead of the fire which the gases may be carried depends on the point at which they are nearly saturated with moisture. If carried farther they begin to deposit moisture on the ware instead of taking it from it. A strong draft is of great importance, as the gases have to travel a much longer distance than they do in other types of kilns.

Continuous kilns are not used nearly as much in this country as abroad, although there seems no reason why they should not be, but it has been suggested that greater care in the construction and operation is necessary in order to insure uniform success.

#### PAVING BRICK.

Many different kinds of clay are utilized in the manufacture of paving brick, although shales perhaps are most favored. None of these occur in the Coastal Plain of Virginia, but they are not uncommon in the western part of the State. Some of the reasons

why shales are found to be so well adapted for the manufacture of paving brick are, that they are so fine grained, and because they often contain the proper quantity of fusible impurities. These two characteristics permit the shale to fuse to a homogeneous mass at a comparatively low temperature. Paving brick materials vary considerably in their composition, but the range shown by 25 selected samples is given below.\*

Components	Minimum	Maximum	Average
Silica ( $\text{SiO}_2$ ) . . . . .	49.00	75.00	56.00
Alumina ( $\text{Al}_2\text{O}_3$ ) . . . . .	11.00	25.00	22.50
Ferric oxide ( $\text{Fe}_2\text{O}_3$ ) . . . . .	2.00	9.00	6.70
Lime ( $\text{CaO}$ ) . . . . .	.20	3.50	1.20
Magnesia ( $\text{MgO}$ ) . . . . .	.10	3.00	1.40
Alkalies ( $\text{Na}_2\text{O}$ , $\text{K}_2\text{O}$ ) . . . . .	1.00	5.50	3.70
Ignition . . . . .	3.00	13.00	7.00

These analyses indicate a somewhat high percentage of iron oxide, lime, magnesia, and alkalies.

Clays used for making paving brick should possess at least fair plasticity since they are commonly molded by the stiff-mud process; and they should vitrify at a comparatively low temperature. The methods of manufacture are essentially the same as those described under building brick.

#### DRAIN TILE.

The clays employed for the manufacture of drain tile are very similar to those used for building brick, care being often taken, however, to use materials as free from grit as possible. They are tempered in the same manner as brick clays and molded in a stiff-mud auger machine, which differs only from that used for brick, in the style of the die.

Drain tile are commonly dried on pallet racks, although at some yards drying floors are employed. They are burned either in a kiln by themselves, or set in with the bricks, in case both are made at the same yard, and are to be burned at the same temperature.

Although a few manufacturers burn their tile to vitrification, the majority are not burned any harder than common brick, so that the temperature ranges usually from cone 010 to cone 05. This is generally sufficient, as the tile do not have to bear any pressure when in use. Being set in the soil, they are subject only to the action of frost.

\*Wheeler, Missouri Geological Survey, Vol. XI, p. 456.

## HOLLOW WARE FOR STRUCTURAL WORK.

Under this title are included fire-proofing, terra-cotta lumber, hollow blocks and hollow bricks. They resemble each other in being hollow, frequently of rectangular outline, and are strengthened by one or more cross-webs or partitions.

*Fireproofing* applies to those shapes 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 out in the kiln, thus leaving the material so soft and porous that nails can be driven in it. It is used chiefly for partitions.

*Hollow blocks* are used for exterior walls in both fireproof and non-fireproof buildings.

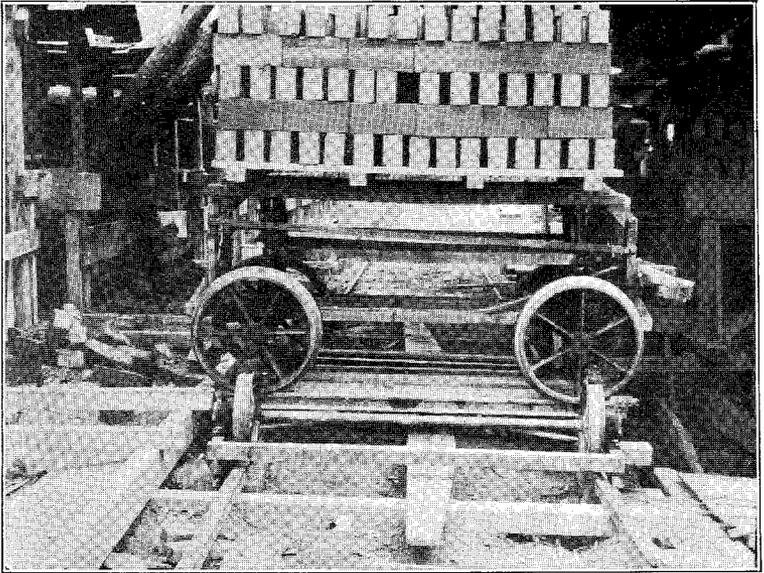
*Hollow brick* are like hollow blocks in form, but little or no larger than ordinary building bricks.

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 in. long, the other two dimensions may be 6 by 3 in., 6 by 4 in., 6 by 5 in., 6 by 6 in., etc. Many different fire-proof 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.

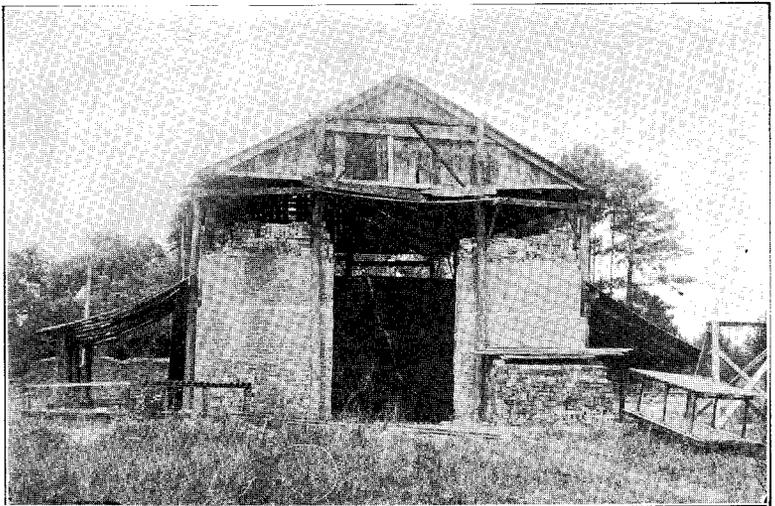
Hollow blocks are usually made in 8 inch lengths, but vary in the other two dimensions, being 4 by 16, 6 by 16, 8 by 16, etc. They are used extensively in the Central States, but not so much in the eastern ones. It is probable that the more plastic Coastal Plain clays of Virginia could be used for this purpose.

The method of preparation and molding is essentially the same as that employed in making stiff-mud brick. The die of course is of special type, which emits a hollow tube with cross partitions. The cutting table is likewise of a specialized type, and so designed that as the brick reaches the end of the table it is turned to an upright position to facilitate handling.

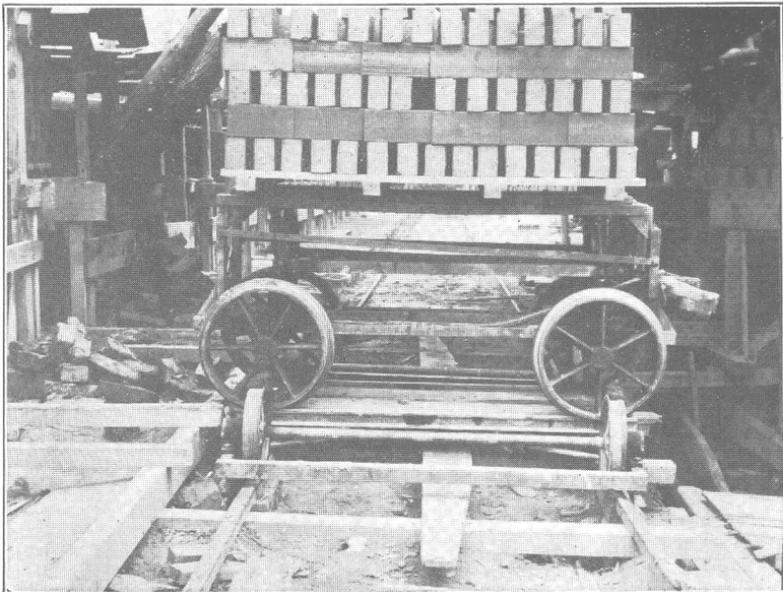
Owing to the peculiar structure of the die, the clays used must flow through it easily, and after burning yield a body sufficiently



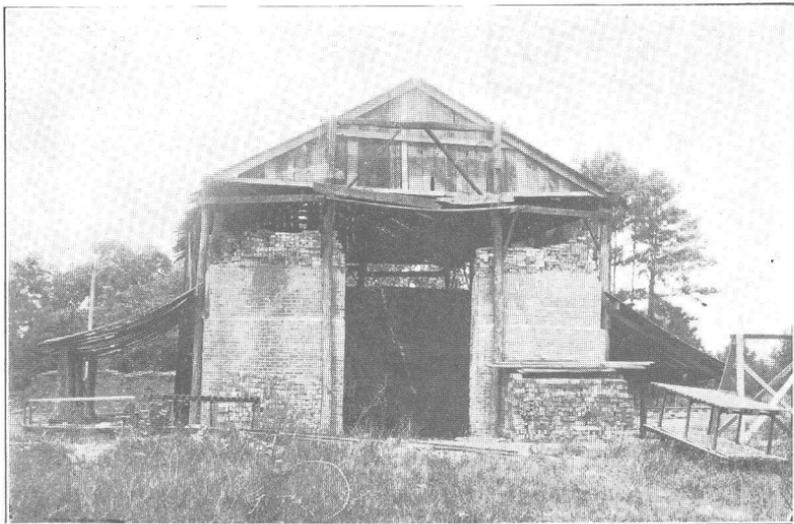
A. Car of green bricks. These are wheeled to the drying shed, where the platform with bricks is set on supports, and the trucks taken back to the molding machine for another load.



B. Up-draft kiln, with permanent side-walls but no roof. Much used in the Coastal Plain area for burning common brick.



A. Car of green bricks. These are wheeled to the drying shed, where the platform with bricks is set on supports, and the trucks taken back to the molding machine for another load.



B. Up-draft kiln, with permanent side-walls but no roof. Much used in the Coastal Plain area for burning common brick.

hard and strong to bear the necessary weight when set in a wall.

Williams 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.

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 composition of clays used for hollow ware varies so, that no one can be selected as typical, but it may be said that several of those analyzed from the Virginia Coastal Plain agree closely with hollow-ware clays used in other states.

#### POTTERY MANUFACTURE.

It seems doubtful whether the clays of the Coastal Plain region, thus far examined, can be used for any form of pottery other than common red earthenware. A few could be employed for a low grade of stoneware, but the product could probably not compete successfully with the cheap stoneware made in Ohio or Pennsylvania, and shipped in enormous quantities to neighboring states.

*Raw materials.*—The clays used for making common red earthenware, such as flower pots, are usually those beds of the poorer grades of clay, which are of good plasticity, free from grit, and burn to a porous, but often steel-hard body at from cone 05 to 03. Some are even burned at 010. Clays of this type are not uncommon in the Pleistocene formations of the Coastal Plain. If they are too dense-burning, even at these low cones, fine sand can be added to preserve the porosity.

Stoneware, at the present day, is usually made of a No. 2 fire clay, which can be burned to a hard, nearly vitrified body, and is also sufficiently refractory to take a slip glaze (an easily fusible clay), or an artificial glazing mixture, which may melt at cone 4 or so.

On this account, low grade clays are undesirable. Those near Curle's Neck, Virginia, for example, are not sufficiently refractory

---

\*Iowa Geological Survey, Vol. XIV., p. 213.

to stand up at the heat required to melt the glazes now commonly used for stoneware. They would require a glaze of very low fusibility or have to be glazed with salt, which can be done at about cone 1.

*Manufacture.*—The clay for pottery manufacture has to be thoroughly mixed in order to render it perfectly homogeneous, and free from air bubbles. To this end it is first tempered in some form of pugmill, and then wedged. This latter operation consists in taking a large lump of the tempered 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. The molding is accomplished by several methods. Turning is done on a rapidly turning horizontal wheel, the potter taking a lump of clay and placing it on a revolving disk. Wetting the surface with a slip of clay and water, he gradually works the whirling mass up into the desired form. After being turned, the object is then detached from the wheel by running a thin wire underneath it, and is set on shelves in the drying room. 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.

Jollying or jiggling 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 plastic 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 with the aid of a template 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 size of flower pots. A pressing machine 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

PHYSICAL TESTS AND CHEMICAL ANALYSES OF THE COASTAL PLAIN CLAYS IN VIRGINIA.

Laboratory No.	Color	LOCALITY	Per. Ct. Water Required	Slaking	Plasticity	Grit	Per Ct. Air Shrinkage	Ave. Tensile Strength Lbs. per sq. in.	CONE 010		CONE 05		CONE 03		CONE 1		CONE 3		CONE 5		CONE 8		CHEMICAL COMPOSITION						Total Fluxes	Lab. No.						
									Fire Shrinkage	Color	Fire Shrinkage	Color	Fire Shrinkage	Color	Fire Shrinkage	Color	Fire Shrinkage	Color	Fire Shrinkage	Color	Fire Shrinkage	Color	Fire Shrinkage	Color	Fire Shrinkage	Color	Fire Shrinkage	Color			Fire Shrinkage	Color	Loss on Ignition	Silica, SiO <sub>2</sub>	Titanium Oxide TiO <sub>2</sub>	Ferric Oxide Fe <sub>2</sub> O <sub>3</sub>
1300	Yel. buff	Brick mixture, Maynard & Powers, Richmond	20.9	Mody. fast	Good	Fine	6.4	89.6	0	Lt. red	17.40	1.6	Lt. red	14.06	5	Red	7.1	6.3	Dk. red	4.04	6.6	Gr. br'n	1.4	1.4	4.61	71.50	1.44	4.78	13.86	.56	.11	2.29	0.81	8.55	1300	
1302	Yel. buff	Fort Lee	24.2	Mody. fast	Good	Little	8.6	60.6	0	Lt. red	20.2	1.6	Lt. red	14.06	6.3	Lt. red	7.5	7	Lt. red	5.9	8.3	Dk. red	2.6	2.6	5.52	69.55	1.06	6.05	15.79	.74	.08	1.54	0.38	8.05	1302	
1305	Gray blk.	Two miles south of Chester	25.3	Fast	Low	Some	9.3	177.3	0	Lt. red	18.2	1.3	Lt. red	12	2.3	M. red	7.54	7	Dk. red	7.65	Viscous	Dk. red	Fused	0	0	4.41	69.74	.06	6	12.64	1.46	1.18	2.54	0.92	13.10	1305
1306	Yel. buff	One mile northwest of Bermuda Hundred	29.7	Fast	Good	Very fine	8.6	148.8	3	Lt. red	22.04	5.7	Lt. red	8.7	10.7	Dk. red	.12	10.3	Dk. red	.11	4.6	Gray	2.11	2.11	5.32	61.83	.08	6.85	21.26	.38	.78	2.44	1.01	11.46	1306	
1307	Yel. buff	Keeler's yard, Broadway on Apomattox River	24.6	Slow	Good	Very little	9.0	138.1	3	Lt. red	17.9	5.0	Lt. red	7.3	8	Red	1.7	9.3	Dk. red	1.8	7	Red gray	1.7	1.7	6.67	59.59	.12	8.07	21.10	.20	.76	2.38	1.06	12.47	1307	
1311	Yel. buff	Sturgeon Point	23.1	Mody. fast	Good	Fine	7.6	122.6	0	Lt. red	16.8	2.3	Lt. red	8.2	5.6	Red	3.9	7	Dk. red	1.9	5.3	Dk. red	1.5	1.5	4.53	68.60	.16	6.41	16.11	.75	.32	2.35	.71	10.54	1311	
1312	Gray	Oldfield	20.3	Slow	Good	Much	7.6	111.5	0	Pink buff	15.04	2	Pk. buff	13.5	3.6	Yel. red	7.2	6	Pk. buff	3.9	6.6	Gray	1.08	1.08	2.81	73.84	1.22	3.39	15.08	.62	.12	2.17	.71	7.01	1312	
1313	Yel. buff	Oldfield	20.9	Mody. fast	Good	Little	8.6	191.0	3	Lt. red	17.5	1.6	Lt. red	9.6	6.3	M. red	5.5	7.6	M. red	4.9	7.6	Dk. gray	1.68	1.68	5.34	68.97	1.28	4.22	16.51	.44	.05	2.59	.56	7.86	1313	
1314	Yel. buff	Ball Property six miles south of east of Richmond	23.1	Mody. fast	Good	Little	7.3	126.7	0	Lt. red	19.5	3	Lt. red	13.1	9.0	M. red	1.5	7.6	Dk. red	.4	3	Dk. r. br.	2.6	2.6	4.10	65.97	1.04	6.74	17.38	1.16	.17	2.46	.93	11.46	1314	
1315	Yel. buff	east of Richmond	24.2	Mody. fast	Excellent	Little	8.6	135.1	0	Pk. cream	16.03	4.3	Pk. buff	12.42	6.5	Gray buff	2.5	8.6	Dk. red	1.01	7	Gray	.7	.7	5.41	63.82	.74	6.32	20.44	.22	.11	2.72	.93	10.30	1315	
1316	Lt. gray	Impure diatomaceous earth	31.6	Fast	Lean	Some	13		.6	Lt. red	14.62	2	Lt. red	12.42	3	Lt. br'n	9.1	3.3	Red br'n	6.9	5	Red gray	5.06	5.06	4.82	66.01	.50	3.59	20.77	.92	1.1	2.52	.74	7.88	1316	
1322	Br. buff	Richmond	34.6	Fast	Lean	Some	14		.6	Lt. red	14.9	2.3	Lt. red	9	5	M. red	4.16	6	M. red	2.30	6	Red gray	1.70	1.70	6.89	63.17	.88	6.32	19.30	.06	.69	2.45	.69	10.21	1322	
1323	Br. buff	Richmond	7	Mody. fast	Good	Sandy	93.7		15.9	1.3	M. red	5.3	3	Dk. red	11.4	3.7	Dk. red	6.2	5.3	Dk. red	3.4	5	Dk. red	1.4	1.4	4.03	73.38	.88	5.53	13.53	.58	.14	2.32	.47	9.04	1323
1324	Yel. buff	W. J. Ready's yard, Manchester, by Richmond	20.3	Mody. fast	Good	Much	7	132	s.s.	Lt. red	17.5	2	Lt. red	12.07	3.6	Dk. red	9.8	4	Dk. red	8.7	5	Dk. red	1.47	1.47	4.85	69.43	.88	6.70	14.79	.57	.63	2.26	.71	10.87	1324	
1325	Brown	chester, by Richmond	18.7	Fast	Fair	Sandy	6	99	s.s.	Lt. red	16.4	.6	M. red	14.4	2	M. red	10.3	3	Dk. red	8.2	5.6	Red	1.6	1.6	3.65	72.61	.44	5.61	13.08	.96	.23	2.45	.93	10.18	1325	
1326	Br. buff	Williamsburg road near Staggs Mill, Richmond	27.8	Slow	High	Some	12.6	300.9	1	Pink	14.4	3	Pink	5.65	7.6	Red br'n	1.07	7.6	Dk. br'n	.08	2	Gray	2.4	2.4	5.29	63.06	.04	6.26	20.90	.16	.45	3.13	.68	10.68	1326	
1330	Gray	Turner's yard near Petersburg	23.1	Slow	Excellent	Little	8	135.5	3	Lt. red	17.09	2	Lt. red	11.80	4.6	M. red	7.8	5	M. red	8.7	7.6	Dk. red	3	3	7.25	61.35	.06	7.10	19.70	.67	.34	2.38	1.11	11.60	1330	
1331	Br. buff	Wood's yard near Emporia	24.0	Slow	Good	Little	8.6	132.4	3	Lt. red	16.30	1	Lt. red	11.90	3	M. red	11.05	3.6	Dk. red	9.9	4.3	Dk. red	6.20	6.20	6.09	67.14	.88	6.21	11.10	1.19	.11	1.95	1.10	10.56	1331	
1333	Lt. br'n	Clays showing variable character of upper bed at Sturgeon Point	24.2	Mody. fast	Fair	Sandy	8.3	144.2	3	Lt. red	17.7	1.6	Lt. red	12.1	4.3	M. red	8.2	5	Dk. red	6.6	4.6	Dk. r. gray	5	5	5.07	69.75	.06	4.67	17.13	.53	.31	1.89	.56	7.96	1333	
1334	Lt. br'n	act of upper bed at Sturgeon Point	18.7	Fast	Fair	Much	6	105.1	0	Pink	15.7	.3	Pink	12.2	1.3	Lt. red	10.3	2.6	Mot. red	9.3	2.3	Lt. red	7.86	7.86	3.03	74.55	.22	3.07	15.43	.43	.65	1.42	1.16	6.73	1334	
1335	Gray	Clay from river level, Surgeon Point	18.7	Fast	Low	Sandy	5	79.8	s.s.	Lt. red	15.08	s.s.	Lt. red	13.9	.0	M. red	12.90	7	Lt. red	12.3	.0	Dir. lt. red	10.91	10.91	3.24	77.78	.20	3.05	12.84	.40	.29	1.69	.44	5.87	1335	
1336	Gray	Point	30.2	Mody. fast	Fair	Little	8	118.7	3	Bluish red	20.54	2	Lt. red	9.81	8.3	Dk. red	2.80	.0	Dk. red	1.5	8.6	Dk. red	.15	.15	7.49	61.21	.74	5.81	20.82	.57	.75	2.57	.73	10.43	1336	
1339	Br. buff	City Point	20.3	Slow	Excellent	Much	7.6	155	.6	Lt. red	17.2	3.3	Lt. red	10.05	6	M. red	4.6	6.3	Dk. red	2.7	6.6	Dk. red	1.3	1.3	7.76	61.06	.16	7.03	19.61	.77	.09	2.34	1.01	11.24	1339	
1343	Gray	Standard Brick Co., south of Suffolk	22	Slow	Excellent	Much	8.6	143.8	1.3	Pinkish	14.6	1.6	Buff	12.6	1.6	Lt. red	10.9	2.3	Lt. red	9.7	3	Lt. yellow	7.01	7.01	5.06	75.79	.08	3.17	14.85	.04	.08	.75	.22	4.26	1343	
1344	Drab	Blue clay, Suffolk Clay Co., Suffolk	31.9	Slow	Excellent	Little	11.6	143.8	1.3	Pink	16.9	4	Pink	6.11	7	Lt. br'n	1.50	7.6	Drab	.20	Beyond vitri.	Lt. gray	Beyond vitri.	Beyond vitri.	Beyond vitri.	6.66	64.39	.08	4.40	20.49	.17	.91	2.31	.54	8.33	1344
1345	Buff	Brick mixture, Suffolk Clay Co., Suffolk	26.4	Slow	Good	Little	10.3	142.5	.6	Pink	15.4	3	Lt. red	7.5	6.6	M. red	2.6	7.3	Dk. red	1.04	7	Gray	.60	.60	5.98	65.55	1.95	5.29	18.13	.39	.51	1.82	.33	8.34	1345	
1350	Pink	Esocene clays from between Stafford C. H. and Fredericksburg	36.3	Mody. fast	Crumbly	Little	9.3	115.3	.6	Lt. red	28.2	2.6	Pink	14.20	9	Lt. red	12.06	9	Lt. red	7.91	10.3	Red br'wn	3.50	3.50	8.63	51.12	.47	10.70	26.14	.10	.25	1.78	.77	12.87	1350	
1352	White	Between Milford and Bowling Green	35.2	Mody. fast	Good	Little	8.6	113.7	.6	Pk. white	25.4	.0	.....	19.6	5	Cream	13.2	6.3	Lt. yellow	13.1	7.6	Yel. buff	8.30	8.30	8.44	57.26	.14	3.10	28.97	.04	.19	1.40	.42	5.15	1352	
1353	Yel. br'n	One mile south of Layton	27.5	Mody. fast	Good	Little	11	193.6	.3	Lt. red	16.6	2	Red br'n	11.79	4	M. red	9.70	4.3	Dk. red	5.32	5	Red br'wn	2.09	2.09	5.09	69.00	.10	6.72	15.88	.06	.15	2.34	.91	10.18	1353	
1354	Gr'n gray	Red clay, northwest of Fredericksburg	24.2	Slow	Low	Much	6	41.2	s.s.	Lt. red	26.80	.0	Lt. red	27.77	1	Lt. red	27	1.6	Red	25.5	2	Lt. br'wn	27.9	27.9	3.55	85.72	.06	1.74	5.83	1.01	.11	1.31	.64	4.81	1354	
1355	Light red	Diatomaceous earth, one mile south of Layton	33.0	Fast	Good	Little	9.6	79.9	.6	Lt. red	28.01	4	M. red	15.40	11	Dk. red	4.08	12.3	Dk. red	1.4	12.6	Dk. red	.18	.18	6.00	55.33	.81	9.02	25.89	.22	.08	2.57	.25	12.14	1355	
1358	Light red	Pleistocene clay, Wilmington	23.1	Fast	Low	Little	10.3	29.4	.6	Lt. red	21.73	.6	Lt. red	15.88	5.6	Pink	11.3	5.6	Red gray	9.5	6	Lt. br'wn	5.4	5.4	3.66	78.82	.33	5.42	9.24	.04	.12	1.51	.81	7.90	1358	
1362	Lt. br'n	Diatom. earth, Wilmington	62.4	Fast	Low	Some	3.6	34.4	1.3	Yellowish	50.96	1.6	Lt. pink	44	4.6	Pk. cream	41.4	4.6	Yellow	40.9	5.3	Yellow	38.3	38.3	4.74	71.60	1.88	4.65	13.18	.42	.66	1.58	1.23	8.54	1362	
1363	White	Clay from "House" bank south of Wilmington	22.0	Mody. fast	Good	Much	7.6	87.1	s.s.	Pk. cream	15.2	.0	Pk. cream	14.4	.3	Pk. cream	14.01	1.3	Yel. br'n	10.72	1.3	Red yel.	11.2	11.2	4.59	77.28	.06	2.42	13.01	.88	.70	1.22	.68	5.02	1363	
1365	Buff	Sandy clay, Occupacia P. O.	26.4	Fast	Fair	Sandy	8.6	54.2	.0	Lt. red	29.89	.6	Lt. red	27.72	2	Pink	23.34	2.3	Lt. red	23.7	2.6	Yel. br'n	23.05	23.05												

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 for pots up to seven inches diameter.

Red earthenware is commonly burned in circular or rectangular up-draft kilns.

---

## CHAPTER V.\*

### DETAILED ACCOUNT OF THE VIRGINIA COASTAL PLAIN LOCALITIES.

The following discussion does not attempt to include every clay deposit in the Virginia Coastal Plain or Tidewater belt. In the time at my disposal the endeavor was made to visit all the deposits which were being actively worked and which appeared to be promising, and it is felt that the results are sufficiently detailed to afford one a fairly accurate idea of the clay resources of this region. In this chapter the subject is discussed from the economic standpoint. The descriptions of the different localities are taken up from north to south and in general from west to east, the main exception being the descriptions of the diatomaceous earth deposits which are grouped by themselves.

The Virginia Coastal Plain region lies east of a line passing through Alexandria, Fredericksburg, Bothwell, Richmond, Petersburg and Emporia, and having an area of approximately 9,500 square miles.

The region is traversed by many southeast flowing rivers, which cut the area into a number of broad low ridges.

The Coastal Plain formations consist in general of a series of clays, sand, and gravels, with some beds of greensand. These beds, which range in age from early Cretaceous to Pleistocene,

---

\*The writer was assisted in the field work for this report by Mr. H. F. Day, a student in geology at the Virginia Polytechnic Institute, and in the laboratory work by Mr. H. Leighton, of Cornell University. Acknowledgments are due to both of these gentlemen for the efficient aid which they rendered.

dip very gently to the east and southeast at the rate of about 10 to 12 feet per mile (according to B. L. Miller), so that if the outcrop of a formation is at the western edge of the Coastal Plain, it would be at a much greater depth near the sea coast. Or, again, if a formation were found at sea level at a point midway between the coast line and the fall line, its dip would carry it higher up if it were followed inland, or lower down if followed toward the coast.

Of the different materials going to make up the deposits, the sands seem to be the most prominent, the clays being found at scattered localities, either on the surface or interbedded with the sands, and rarely forming deposits of great extent. In fact they seem in most cases to be of lenticular or lens-shaped character. The majority are red-burning, while only a few are buff-burning. No white-burning clays have been found; but even though they lack in variety so far as their color-burning qualities are concerned, it is probable that their possible uses are more numerous than is now supposed, and it is hoped that the tests given in this report may serve to encourage their development.

---

#### ALEXANDRIA COUNTY.

##### THE ALEXANDRIA AREA AND VICINITY.

This area is the most important brick-making district in the Virginia Coastal Plain region. It cannot be said that this marked local expansion of the clay-working industry is due to the more abundant occurrence of clay at this point, but rather to the fact of its nearness to an active and important market, namely, the city of Washington. Nearly all the brick yards of the area here described are situated so close to the city, that the product is hauled across the river by teams, and the daily continuous procession of wagons loaded with brick indicates the demand for the Virginia product.

The clays used in the Alexandria district are the Columbian loams, which underlie the low hills around Alexandria, Arlington, Addison, Riverside, etc.\* They are all sandy loams of variable color, yellow, red, brown and bluish gray, and are frequently of

---

\*Their distribution is shown on the Washington Folio, of the U. S. Geological Survey.

mottled character. Most of the clays burn to a red brick, but certain ones show a tendency to fire buff, and since these lighter burning parts are oftentimes tougher, they do not mix readily with the red-burning clay when the run of the bank is used, so that the buff spots show in the brick after burning. At the yard of the Washington Hydraulic Pressed Brick Company, the several clays are carefully separated and burned alone, thus giving several different shades of product.

Owing to the extent of the deposits and the amount of clay used, many of the yards dig their clay with a steam shovel, this being a rapid and economical method, but one to be employed only when the clay can be mixed from the top to the bottom of the bank. At the hydraulic works, where the different beds are separated, a wheel scraper or special form of clay gatherer is employed.

At most of the yards the clay is put through a pair of rolls, and pugmill before it passes to the press. Several types of the latter are used in this area. At one or two yards molding is done by hand; an equally small number use a stiff-mud machine, and one a dry press. The majority, however, use a peculiar type of machine known as the Trenton Wheel Machine. This consists of two large wheels, revolving slowly in opposite directions. A series of mold boxes, is set into the rim of one of these, each mold box having an easily movable bottom, to which is attached a thick stem, which passes through a plate set below the mold. As the wheel revolves, the movable bottom falls to the bottom of the mold as it comes on top of the wheel, and rises in the mold relatively, but actually drops, as any one mold reaches its lowest point in the revolution of the wheel. Two screen boards fit up closely against the rim of the wheels where these converge above, the boards and edges of the wheels thus forming a sort of hopper. As the wheels revolve the clay is charged into the hopper, and falling in between the rims of the wheels as they go around, is forced into the molds. As the filled mold reaches its lowest or inverted position, the movable bottom drops and the green brick is pushed out onto a belt. The brick is rather rough and granular even for a common one, and it is usually repressed. It is remarkable to find this machine so extensively used at this one locality for common brick making, as it takes up much space, requires much power, is cumbersome, of

limited capacity, and does not give any smoother product than a soft-mud machine. At those yards where stiff-mud machines are employed, they seem to give good results.

Drying is done on open yards, on pallets, or in a number of cases in tunnel driers. Throughout the Alexandria region, the kilns employed are with few exceptions up-draft with permanent side walls. A few use scove kilns, and the Hydraulic Company has down-draft ones.

The firms in operation in this region are: Washington Hydraulic Pressed Brick Company; Jackson-Phillips Company; Potomac Brick Company; Virginia Brick Company; Estate of Charles Ford; Walker Brick Company; West Bros.; Alexandria Brick Company; Washington Brick and Terra Cotta Company; and American Hygienic Brick and Tile Company. The last is located near Riverside.

---

#### SPOTTSYLVANIA COUNTY.

##### THE FREDERICKSBURG AREA.

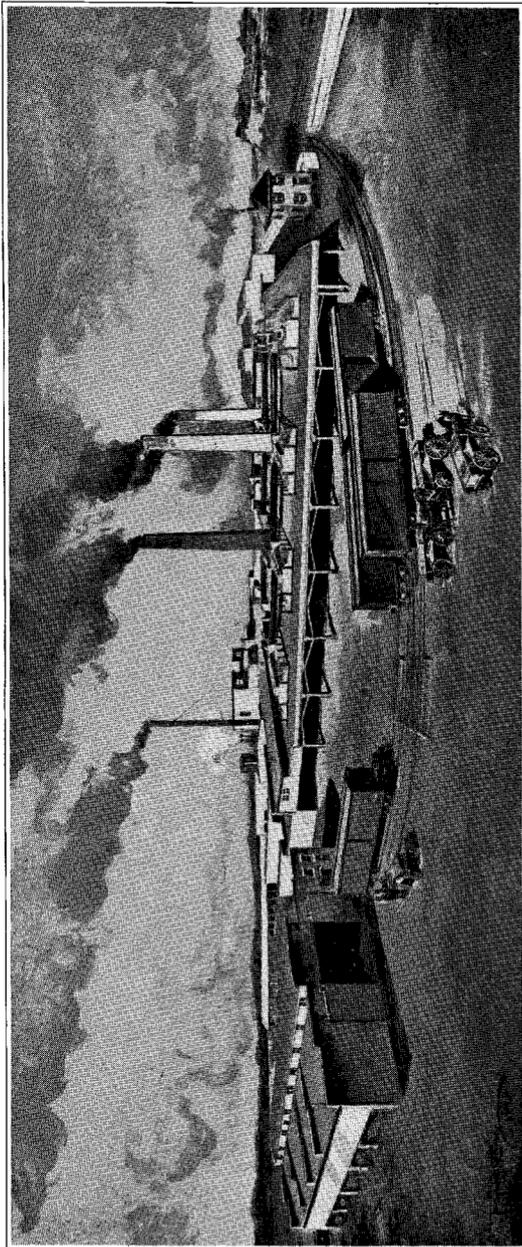
There is only one small yard at this locality, namely, that of the Fredericksburg Brick Works, which is located on the western edge of the town. The material used is a red silty clay, containing small angular quartz grains, and is possibly a residual clay, which has been worked to some extent by water. The material burns to an excellent red color, but not to a very dense body. It is utilized for common brick, and molded in an end-cut auger machine, it being claimed that fewer cracked bricks are obtained than when a soft-mud machine was used. The bricks are dried on pallets and burned in Dutch kilns.

The most prominent clays in the region around Fredericksburg are those belonging to the Eocene formation. While these no doubt underlie a considerable area between Fredericksburg and Stafford to the north, still prominent outcrops of them are not very abundant.

The nearest of these to Fredericksburg is located along the road from Fredericksburg to Davis' granite quarry on the hill leading up from the canal. This material, which is of a bright red color, is known, locally, as paint clay, and is said to have been used by the Indians for that purpose. How extensive the bed is can only be determined by boring, for no outcrops of it are seen, except along the

COASTAL PLAIN CLAYS OF VIRGINIA.

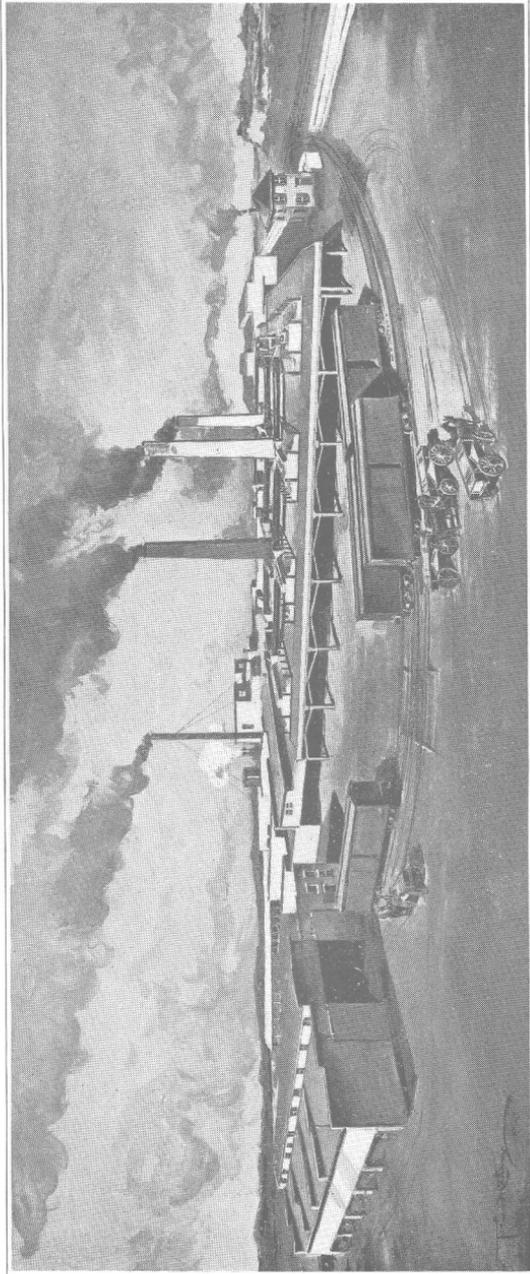
Plate IX.



View of Washington Hydraulic-Press Brick Company's Works.

COASTAL PLAIN CLAYS OF VIRGINIA.

Plate IX.



View of Washington Hydraulic-Press Brick Company's Works.

road, but there it is exposed in the ditch at the roadside for several hundred feet at least. The clay (Lab. No. 1356) which slakes down fast, works up to a very plastic mass with 33 per cent. of water, and has but little grit. The air shrinkage is 9.6 per cent., and the average tensile strength is 79.9 pounds per square inch. In burning it behaved as follows:

WET-MOLDED BRICKLETS.

Cone.....	010	05	03	1	3	5	8
Fire shrinkage.....	.6	4	6	11	12.3	12.6	13.3
Color.....	lt. red	lt. red	red	dk. red	dk. red	dk. red	dk. red
Absorption.....	28.01	21.70	15.40	4.08	1.4	.18	.02

DRY-PRESSED BRICKLETS.

Cone.....		1	3
Fire shrinkage.....		8	9
Color.....		dk. red	red
Absorption.....			11.45

Its chemical composition was:

Silica (SiO <sub>2</sub> ) .. . . .	55.33
Alumina (Al <sub>2</sub> O <sub>3</sub> ) .. . . .	25.69
Ferric oxide (Fe <sub>2</sub> O <sub>3</sub> ) .. . . .	9.02
Lime (CaO) .. . . .	.22
Magnesia (MgO) .. . . .	.08
Soda (Na <sub>2</sub> O) .. . . .	.25
Potash (K <sub>2</sub> O) .. . . .	2.57
Titanic oxide (TiO <sub>2</sub> ) .. . . .	.81
Ignition .. . . .	6.00
	99.97
Total fluxes .. . . .	12.14

This is a red-burning clay which reaches steel hardness at cone 1, burning to a rich red color at that heat, but showing a sudden and marked increase in its fire shrinkage. The total shrinkage of this clay is too high to permit its being used alone for the manufacture of clay products. At cone 8 it is practically vitrified. The main use of this clay would seem to be for the manufacture of mineral paint.

Following the road from Fredericksburg to Stafford, there are a number of indications of bluish-white Eocene clay in the ditches along the road side but most of these are topped by a heavy bed of sand. About six miles east of north from Fredericksburg, a heavy bed of the clay is found on top of a ridge.

The section here involves:

Surface sand and soil . . . . .	1—2 feet
Pink clay, laminated . . . . .	12 feet
Whitish clay . . . . .	4 feet

The pink clay (Lab. No. 1350) is distinctly stratified and in its upper part contains some scattered crusts of limonite. It slakes fairly fast, and works up with 36.3 per cent. water to a mass of moderate plasticity and little grit, whose air shrinkage is 9.3 per cent. and whose average tensile strength is 115.3 pounds per square inch. In burning it behaved as follows:

## WET-MOLDED BRICKLETS.

Cone.....	010	05	03	1	3	5	8
Fire shrinkage.....	.6	2.6	3.6	7	9	10.3	10.3
Color.....	light red	pink	light red	light red	light red	red brown	red brown
Absorption.....	23.2	23.1	14.20	12.06	7.91	3.50	3.74

## DRY-PRESS BRICKLETS.

Cone.....	1
Fire shrinkage.....	7
Color.....	light red

Its chemical composition was:

Silica (SiO <sub>2</sub> ) . . . . .	51.12
Alumina (Al <sub>2</sub> O <sub>3</sub> ) . . . . .	26.14
Ferric oxide (Fe <sub>2</sub> O <sub>3</sub> ) . . . . .	10.70
Lime (CaO) . . . . .	.10
Magnesia (MgO) . . . . .	.25
Potash (K <sub>2</sub> O) . . . . .	1.78
Soda (Na <sub>2</sub> O) . . . . .	.77
Titanic oxide (TiO <sub>2</sub> ) . . . . .	.47
Ignition . . . . .	8.63
	99.96
Total fluxes . . . . .	12.87

The clay, although burning to a good color, is not a dense-burning one, in fact it does not yield as tight a body as some of the Pleistocene clays. It burns steel-hard at cone 1, but does not make a product of low absorption until cone 8 is reached. Its main use would be for common brick, pressed brick or drain tile. It seems too low in plasticity to work on a stiff-mud machine. The outcrop mentioned is somewhat distant from the railroad for cheap exploitation, but the extension of this bed should be found to the westward, nearer lines of transportation.

The whitish clay (Lab. No. 1352) which underlies the pink clay, slakes moderately fast and works up with 35.2 per cent. of water to a mass of good plasticity whose air shrinkage is 8.6 per cent. and the average tensile strength 113.7 pounds per square inch.



The blue clay, which is of Pleistocene age, is mixed with either the diatomaceous clay, or with clay from another surface deposit not far distant. The green sandy clay, which is the same as that tested from Layton, lies below the level of the yard. Pl. XV, Fig. 1. shows the Pleistocene clay overlying the diatomaceous earth.

Another deposit of Pleistocene clay, known as the House Clay, is dug about one-fourth mile northeast of the brick works. Here the clay runs from 9 to 13 feet in thickness and is underlain by sand. Still another deposit has been located one-half mile northwest of the brick yard. Only the House Clay (Lab. No. 1365) and that at the brick yard (Lab. No. 1362) were tested. Their properties were as follows:

	1362	1365
Water required.....	19.2	22
Slaking.....	mod. fast	mod. fast
Plasticity.....	good	good
Grit.....	some	much
Air shrinkage.....	7.3	7.6
Average tensile strength.....	130.8	87.1

## WET-MOLDED BRICKLETS.

<i>Cone 010</i>		
Fire shrinkage.....	0	s. s.*
Color.....	light red	pink cream
Absorption.....	12.84	15.2
<i>Cone 05</i>		
Fire shrinkage.....	0	0
Color.....	light red	pink cream
Absorption.....	12.00	14.4
<i>Cone 03</i>		
Fire shrinkage.....	1	.3
Color.....	light red	pink cream
Absorption.....	10.3	14.01
<i>Cone 1</i>		
Fire shrinkage.....	2.6	1.3
Color.....	light red	yel. brown
Absorption.....	8.5	12.22
<i>Cone 3</i>		
Fire shrinkage.....	2.3	1.6
Color.....	light brown	brown
Absorption.....	6.1	10.72
<i>Cone 5</i>		
Fire shrinkage.....	3	1.3
Color.....	red	buff
Absorption.....	5.9	11.2
<i>Cone 8</i>		
Fire shrinkage.....	4.3	2.3
Color.....	br. buff	buff
Absorption.....	2.03	9.87

\*Slightly swelled.

## DRY-PRESS BRICKLETS.

	1362	1365
<i>Cone 1</i>		
Fire shrinkage .....	1	0
Color .....	brown	buff
<i>Cone 3</i>		
Fire shrinkage .....	1	
Color .....	red	
Absorption .....	15.57	

## CHEMICAL COMPOSITION.

Silica (SiO <sub>2</sub> ) .....	71.60	77.28
Alumina (Al <sub>2</sub> O <sub>3</sub> ) .....	13.18	13.01
Ferric oxide (Fe <sub>2</sub> O <sub>3</sub> ) .....	4.65	2.42
Lime (CaO) .....	.42	
Magnesia (MgO) .....	.66	.70
Potash (K <sub>2</sub> O) .....	1.58	1.22
Soda (Na <sub>2</sub> O) .....	1.23	.68
Titanic oxide (TiO <sub>2</sub> ) .....	1.88	.06
Ignition .....	4.74	4.59
	99.94	99.96
Total fluxes .....	8.54	5.02

Although these clays are both surface clays, and occur in the same formation, at no great distance from each other, still they are quite dissimilar in many respects.

No. 1362 is a red-burning clay which burns to a good bright color. Its air shrinkage is not excessive and its fire shrinkage is low. It contains some coarse grit which shows up clearly on the fractured surface of the burned bricklet. At cone 8 portions of the clay become viscous. This is not a fire clay, but it works well for brick and fireproofing.

No. 1365 is a gritty, light-burning clay which does not burn steel-hard until cone 5, and even at 8 still shows a rather high absorption. Its low air shrinkage and low tensile strength are characteristic of sandy clays. The material can be classed as a low-grade fire clay, such as is used in terra-cotta manufacture, or for boiler-setting brick. It is the most refractory of the series tested from the Coastal Plain area.

The brick works at Wilmont (Pl. XV, Fig. 2.) produce fireproofing, boiler brick and some front brick. In each case a mixture of the Pleistocene clays, or of these with the diatomaceous earth is used.

The clays are molded on either a stiff-mud or soft-mud machine, and dried in tunnels. Burning is done in up-draft kilns. The product is all shipped by water, as the yard is located on the bank of the Rappahannock river.





are filled with limonite. Along the Rappahannock river there are long exposures of the diatomaceous earth. In places it forms great bluffs of a yellowish white color, which stand out prominently in the sunlight and can be seen for a long distance (Pl. XIV, Fig. 2.). This earth appears to be purer and lighter than that around Richmond, but still in places it passes into a clay.

Samples were collected from several localities and examined with some care. Microscopically examined they proved to be somewhat disappointing for the reason that most of them contained very few diatoms, and in some, which to the feel appeared like diatomaceous earth, hardly any diatoms could be found. This is due to the fact that the diatoms are not uniformly distributed through the deposit, but are found chiefly in certain layers. The results of the physical and chemical tests are given below :

Lab. No.	1322	1323	1358	1363
Color, moist.....	brown buff	buff	light yellow	white
Water required.....	31.6	34.6	23.1	62.4
Slaking.....	fast	fast	fast	fast
Plasticity.....	lean	lean	low	low
Grit.....	some	some	little	some
Air shrinkage.....	13	14	10.3	3.6'
Average tensile strength....			29.4	34.4
<i>Cone 010</i>				
Fire shrinkage.....	.6	.6	.6	1.3
Color.....	light red	light red	light red	yellowish
Absorption.....	14.62	14.9	21.73	50.96
<i>Cone 05</i>				
Fire shrinkage.....	.6	2.3	.6	1.6
Color.....	light	light	light	light pink
Absorption.....	13.6	10.9	20.70	48.4
<i>Cone 03</i>				
Fire shrinkage.....	2	3.3	2.3	1
Color <sup>a</sup> .....	light red	light red	light red	pink
Absorption.....	12.42	9.0	15.88	44.70
<i>Cone 1</i>				
Fire shrinkage.....	3	5	5.6	4.6
Color.....	light brown	medium red	pink	pk. cream
Absorption.....	9.1	4.16	11.3	41.4
<i>Cone 3</i>				
Fire shrinkage.....	3.3	6	5.6	4.6
Color.....	red brown	medium red	red gray	yellow
Absorption.....	6.9	2.30	9.5	40.9
<i>Cone 5</i>				
Fire shrinkage.....	5	6	6	5.3
Color.....	red gray	red gray	light brown	yellow
Absorption.....	5.06	1.70	5.4	38.3
<i>Cone 8</i>				
Fire shrinkage.....	2	5.5	6.3	5.6
Color.....	brown	red gray	light brown	yellow br.
Ab-orption.....	2.04	1.08	2.57	32.32

The following analyses of the earths collected from different points show their chemical composition:

Silica (SiO <sub>2</sub> ) . . . . .	70.42	63.17	78.82	82.85
Alumina (Al <sub>2</sub> O <sub>3</sub> ) . . . . .	15.15	19.30	9.24	6.76
Ferric oxide (Fe <sub>2</sub> O <sub>3</sub> ) . . . . .	5.17	6.32	5.42	2.34
Lime (CaO) . . . . .	.14	.06	.04	.35
Magnesia (MgO) . . . . .	.79	.69	.12	1.06
Potash (K <sub>2</sub> O) . . . . .	2.24	2.45	1.51	1.07
Soda (Na <sub>2</sub> O) . . . . .	.39	.69	.31	.99
Titanic oxide (TiO <sub>2</sub> ) . . . . .	.44	.88	.33	1.09
Ignition . . . . .	5.21	6.39	3.66	3.40
	99.95	99.95	99.95	99.91
Total fluxes . . . . .	8.73	10.21	7.90	5.31

The location of these samples is as follows:

No. 1322. Weathered diatomaceous earth from 7th St., near Richmond Locomotive Works, Richmond. This, after burning, closely resembles the diatomaceous earth from along the Rappahannock river near Layton. It seems to be vitrified at cone 5, and at cone 8 is viscous.

No. 1323. This sample was also collected from the same locality as No. 1322, but farther from the surface. It is quite impure, and shows a high air shrinkage. It burns red and becomes steel-hard at cone 05. It is vitrified at cone 5, and nearly viscous at cone 8.

No. 1358. Diatomaceous earth from along the Rappahannock river south of Layton. This burns fairly dense at the higher cones, and gives a clean color, but is quite porous at the lower cones.

No. 1363. Diatomaceous earth from Wilmont. This burns to a very porous body as can be seen from the absorption figures. It has a low air and fire shrinkage.

It will be seen from an inspection of the chemical analyses that these earths show much variation in their chemical composition. All are quite siliceous, and one of them highly so. Nos. 1322 and 1323 represent the fresh and weathered parts respectively of the same bed. The weathered material is more siliceous and contains a lower quantity of fine particles and soluble substances, due probably to the leaching action of water filtering through it from the surface. The higher silica content seems also to affect its porosity and shrinkage in burning. It will also be noticed that the most siliceous one, namely, No. 1363 from Wilmont, is exceedingly porous after being burned.

*Uses of diatomaceous earth.*—Though occurring in Virginia in great abundance, the deposits of diatomaceous earth are but little worked. There are several uses to which the material has been put, the most important of which is as an abrasive. For fine polishing or rubbing it should be of value, since the small, siliceous diatom cases

possess more or less cutting power, but as the abrasive action depends on these, it is quite evident that the presence of clay impurities will decrease the abrasive power of the material. This probably accounts for the failure of much of the Virginia earth to be employed for such purposes. In this connection it should be stated that some of the Virginia material contains a large number of diatoms, and it is such beds that should be chosen. A microscopical examination will at once show whether or not the material contains many diatoms.

A second use of diatomaceous earth is for the manufacture of boiler coverings. For this purpose it is commonly mixed with asbestos, and gives a mixture which forms an excellent non-conductor of heat.

Diatomaceous earth has also been employed as an absorbent for nitroglycerine in the manufacture of dynamite, but little is now used for that purpose.

#### CAROLINE COUNTY.

##### THE MILFORD AREA.

Along the road from Milford to Bowling Green, and about three-quarters of a mile from the former locality, there is a promising deposit of yellowish brown Pleistocene clay, 10 to 12 feet thick. The bed is underlain by sand, but has very little overburden. It (Lab. No. 1353) works up with 27.5 per cent. of water, and has good plasticity, but its air shrinkage is high, namely, 11 per cent. The average tensile strength is 193.6 pounds per square inch. Its behavior in burning was as follows:

##### WET-MOLDED BRICKLETS

<i>Cone</i> .....	010	05	03	1	3	5	8
Fire shrinkage.....	.3	2	2	4	4.3	5	5
Color.....	lt. red	lt. red	red br.	red	red	red br.	red br.
Absorption.....	16.6	13.3	11.79	9.70	5.32	2.09	2.02

##### DRY-PRESS BRICKLETS

<i>Cone</i> .....		1	3
Fire shrinkage.....		3	3
Color.....		dk. red	gray
Absorption.....			41.34

The chemical analysis yielded:

Silica ( $\text{SiO}_2$ )	69.00
Alumina ( $\text{Al}_2\text{O}_3$ )	15.58
Ferric oxide ( $\text{Fe}_2\text{O}_3$ )	6.72
Lime ( $\text{CaO}$ )	.06
Magnesia ( $\text{MgO}$ )	.15
Potash ( $\text{K}_2\text{O}$ )	2.34
Soda ( $\text{Na}_2\text{O}$ )	.91
Titanic oxide ( $\text{TiO}_2$ )	.10
Ignition	5.09
	99.95
Total fluxes	10.18

This is a red-burning surface clay, which becomes steel-hard at 03, but is too gritty to use for any purpose except common-brick manufacture. It would possibly work on a dry press machine.

#### HENRICO COUNTY.

##### THE RICHMOND AREA.

Richmond, next to Alexandria, is the most important clay working center in the Coastal Plain region of Virginia, there being a number of yards engaged in the manufacture of common and in some cases pressed brick. Most of these are located on the edge of Richmond and in the suburbs of Manchester and Fulton, while a few are located near the reservoir and race track.

The output of these is not sufficient to supply the demand, and some outlying towns are also drawn upon. The better grades of pressed brick in Richmond are not made in the Coastal Plain area. Some are obtained from Clayville, Va., but most of them come from points outside of the State.

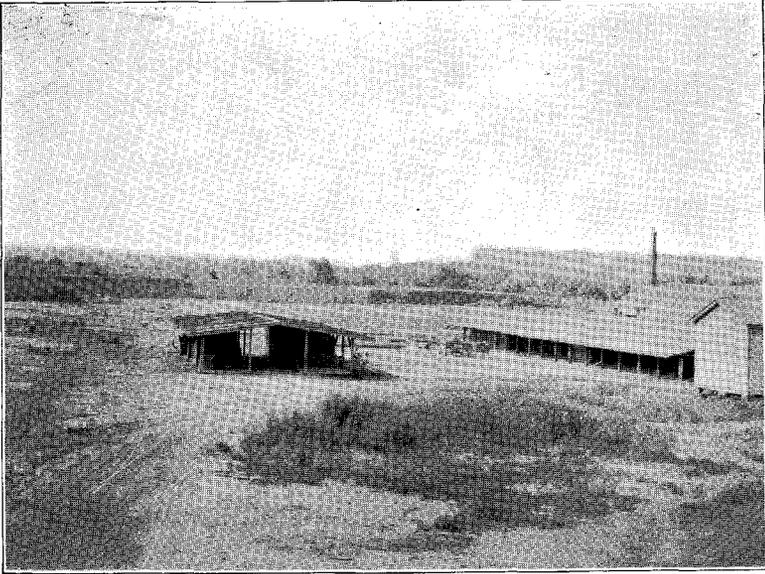
There are four yards in operation in Manchester, all of them being located in the vicinity of Knight and Maury streets. All of these are engaged in the manufacture of soft-mud brick and a few of them also produce a small quantity of pressed brick. The clay used is a more or less mottled, gritty, yellow or reddish clay, which is covered by a thin layer of sandy soil and commonly underlain by a bed of sand. At only one point, namely, the yard of Green and Harrison, is an underlying crystalline rock encountered. The clays in general are very tough and plastic, sometimes quite sandy, and they contain a variable quantity of stony material which ranges in size from small pebbles up to large boulders, most of these being of crystalline character. This stony material is not found to be uniformly distributed through all the

beds, but seems to run rather in streaks, the greatest quantity of it having been observed in the bank of W. J. Ready, and Green and Harrison (Pl. X, Fig. 2.).

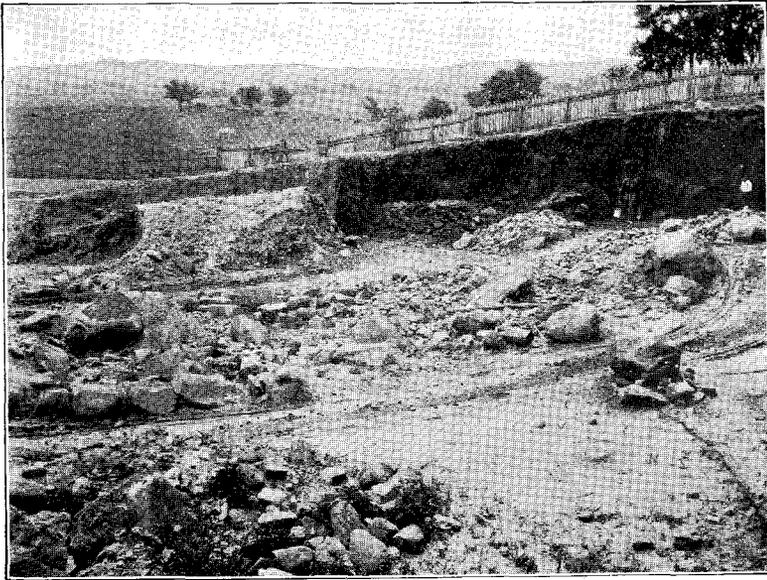
At G. E. Redford's yard (Pl. X, Fig. 1.) the clay shows an average thickness of 12 feet with a maximum of 17 feet, and is underlain by a hard bed of sand and gravel. It is a mottled gritty clay with scattered mica fragments and many limonite stains running through it; and it contains also many decomposed pebbles of crystalline rock. The clay pit is a large shallow excavation lying to the south of the yard and the working face has a height of from 6 to 8 feet. The material is red-burning and for the manufacture of bricks the run of the bank is commonly used. This is necessary because the clay seems to vary somewhat in its physical character. Thus, for instance, it is not safe to use that found in the north end of the pit alone, because it is very tough and cannot be used without cracking. It is mixed in, therefore, with the more sandy portions of the bed. The brick are molded by hand and dried in open yards and burned in up-draft kilns with permanent side walls. The fuel used is wood or coal. When there is a call for front brick some of the hand-molded ones are repressed in a hand-power machine.

Adjoining the yard of Redford on the west is that of W. B. Davis. This pit, which is a large shallow excavation, lies to the south of the yard, and has a working face of from 6 to 7 feet in height. The clay is similar to that in Redford's bank, but seems to contain fewer stones. It is claimed that it runs 20 to 25 feet in depth, and is underlain by whitish sand. The bricks are molded by hand, dried on open yards, and burned in up-draft kilns, with permanent side walls. The fuel used is wood and coal.

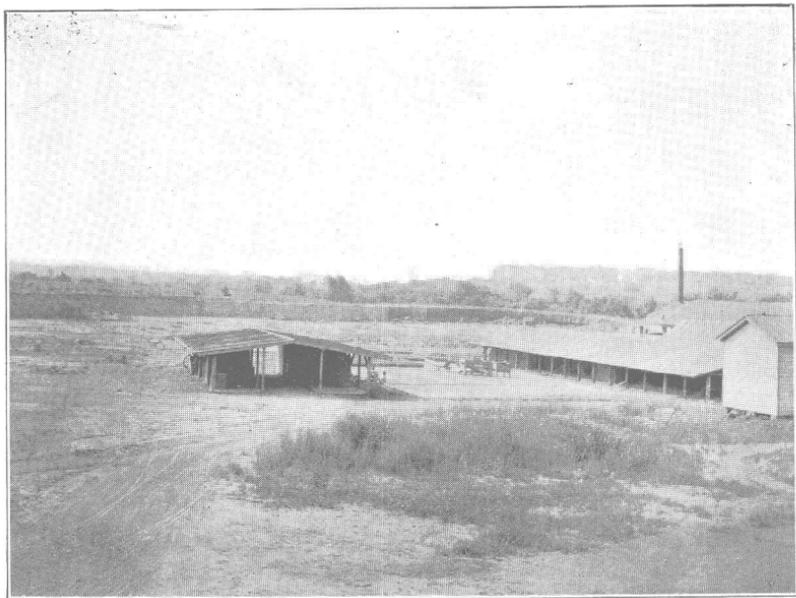
Adjoining Davis' yard on the east is that of W. J. Ready. The clay pit which lies to the northwest of the yard is much deeper than the neighboring excavations and also lies at a slightly lower level, for the upper surface of the clay is uneven and slopes towards the river. The clay in general is somewhat similar to that found at the two preceding yards but contains more stones and boulders than are found in either Redford's or Davis' bank. The thickness of the clay is said to be at least 18 feet, and it is probably underlain by sand. Here in a working face of perhaps 200 feet in length they recognize three different kinds of clay, only one



A. General view of Redford's clay bank and brick yard, Manchester.



B. View of a clay pit at Manchester by Richmond, showing the boulders found at times in the clay of this vicinity,



A. General view of Redford's clay bank and brick yard, Manchester.



B. View of a clay pit at Manchester by Richmond, showing the boulders found at times in the clay of this vicinity,



No. 1324, which was taken from the northwest corner of the bank, can be used alone. This burns to a good red color up to cone 03, but above that it deepens so that it becomes unsightly. At cone 5 it is very close to viscosity.

No. 1325, taken from the west side of the bank, is too tough to be used alone, and is mixed with 1326. When wet it is very plastic, even though quite gritty. At the same time it does not burn to a very dense body, and it has a comparatively low fire shrinkage. It becomes steel-hard at cone 1, and at cone 8 has reached the point of viscosity.

No. 1326, from the southeast corner of the bank, is very sandy, with a low fire shrinkage, and does not work well alone.

W. J. Ready also operates a plant near the West End yard, which is located a quarter of a mile west of the track near the reservoir. The material is the usual mottled surface clay which is worked to a depth of about 7 feet, although a total thickness of 20 feet is claimed for it. No information could be obtained regarding the character of the underlying material. Overlying the clay are about 4 feet of loamy material which is probably the weathered clay. For brick manufacture the run of the bank is used, the clay being tempered in a ring pit, molded on a soft-mud machine, and burned in Dutch kilns. The product consists entirely of common brick and no repressing is done at this yard.

Green and Harrison have a yard located just east of W. J. Ready's. The pit is a small one and contains a large quantity of boulders (Pl. X, Fig. 2.), while in the northwest corner of it the underlying gneiss has been struck. The clay is worked up by the same methods as those used at the adjoining yards.

The yard of the Fulton Brick Company, which is commonly spoken of as Westford's yard, is located west of the Chesapeake and Ohio Railway round house. The clay used here is the ordinary surface clay and does not seem to run over 10 feet in thickness. It also contains many cobble stones. Underlying this is a fine sand which is at least 8 feet deep and is used for sanding the brick molds. The clays here are tempered in ring pits molded by hand and burned in Dutch kilns. The product is almost exclusively common brick.

The Baltimore Brick Company operates two yards at Rockett, a suburb of Richmond. The yards are located near the intersection of Ohio and Williamsburg Avenues. The clay is tempered in ring pits, molded by hand, and burned in Dutch kilns. Some 12 years ago the company tried making soft-mud machine brick but gave it up for some unknown reason. The clay is obtained from under the surface at several points in the vicinity of the yard and averages from 15 to 18 feet in thickness with an underbedding of sand. The material is quite similar in its character to that at Manchester, but lacks the stones and boulders. At the more southerly of the two yards operated by the Baltimore Brick Company the clay is also molded by hand and burned in Dutch kilns. The product has a good ring but is not very smooth or bright in color.

Maynard & Powers operate a pit lying to the southeast of the Baltimore Brick Company's excavation. The working face here is about 12 feet high and shows a sandy, mottled, yellowish brown and gritty clay similar to that occurring in the other pits in this vicinity. The company claims that their clay runs 20 feet in depth and is underlain by a bluish gray sand. The properties of a sample (Lab. No. 1300), representing the run of the bank and used for brick manufacture, are as follows: Color, when moist, yellow buff; water required, 20.9 per cent.; slaking, moderately fast; plasticity, good; grit, fine; air shrinkage, 6.4; average tensile strength, 89.6. When burned the clay behaved as follows:

Cone .....	010	05	03	1	3	5	8
Fire shrinkage .....	0	1.6	1.6	5	6.3	6.6	6.3
Color .....	lt. red	lt. red	lt. red	red	dk. red	gray br.	red br.
Absorption .....	17.40	15.08	14.06	7.1	4.04	1.4	1.29

A dry-press bricklet burned to cone 1 had a fire shrinkage of 4 per cent. and burned to a light red color. This clay is to be classed as a common-brick clay which burns steel-hard at 05 and has an excellent red color at that cone. It gives a rather rich red at cone 1 but at cone 3 the color is too deep and impure to make a nice looking brick.

At cone 5 it appears to be vitrified, but contains too much fine grit to make a good paving-brick body. It is probable that in using this clay for brick manufacture it is not burned at a higher temperature than cone 010.

The chemical analysis of this clay yielded :

Silica (SiO <sub>2</sub> )	71.50
Alumina (Al <sub>2</sub> O <sub>3</sub> )	13.86
Ferric oxide (Fe <sub>2</sub> O <sub>3</sub> )	4.78
Lime (CaO)	.56
Magnesia (MgO)	.11
Potash (K <sub>2</sub> O)	2.29
Soda (Na <sub>2</sub> O)	.81
Titanic oxide (TiO <sub>2</sub> )	1.44
Ignition	4.61
	99.96
Total fluxes	8.55

At the yard where it is used the clay is tempered in ring pits, molded by hand, dried on open yards and burned in Dutch kilns, of which the company has three. The product is sold chiefly in Richmond.

A clay very similar in appearance to that on the Ball property, 6 miles south of the city and probably of the same age is also found outcropping on the Williamsburg road leading to Stagg's Mill, about one-half mile to the west of where the road crosses the railroad. The clay is exposed on a sloping hillside, and in such a position that a large quantity can be removed without having to take off much overburden. It is also well located for shipment. As far as could be ascertained the bed is not less than 20 feet thick. It (Lab. No. 1330) is a grayish clay, which slakes slowly and works up with 27.8 per cent. water to a mass of high plasticity. Its air shrinkage, 12.6 per cent., is somewhat high; so also is the average tensile strength, namely, 300.9 pounds per square inch. In burning, it behaved as follows:

#### WET-MOLDED BRICKLETS.

<i>Cons</i>	<i>010</i>	<i>05</i>	<i>03</i>	<i>1</i>	<i>3</i>	<i>5</i>	<i>8</i>
Fire shrinkage.....	1	3	5	7.6	7.6	2	.3
Color.....	pink	pink	lt. red	red	dk. red	gray	drab
Absorption.....	14.4	8.9	5.65	1.07	.08	2.4	1.56

The chemical composition is :

Silica (SiO <sub>2</sub> )	63.06
Alumina (Al <sub>2</sub> O <sub>3</sub> )	20.90
Ferric oxide (Fe <sub>2</sub> O <sub>3</sub> )	6.26
Lime (CaO)	.16
Magnesia (MgO)	.45
Potash (K <sub>2</sub> O)	3.13
Soda (Na <sub>2</sub> O)	.68
Titanic oxide (TiO <sub>2</sub> )	.04
Ignition	5.29
	99.97
Total fluxes	10.68

This is a very plastic clay which becomes steel-hard at cone 05. It gives a light red color up to cone 03, but at cone 1 gives an excellent dark red color. Its point of vitrification is apparently reached at about cone 3, and at cone 5 it was well passed vitrification and had swelled considerably. It is not as good a clay as that described from near Bermuda Hundred (Lab. No. 1317) or Curle's Neck (Lab. No. 1314).

THE FORT LEE AREA.

At Fort Lee on the Chesapeake and Ohio Railway about 2 miles south of Richmond there is a group of yards operated, respectively, by C. H. Oliver, J. M. Davis and the Fulton Brick Company. The general run of the clays is not unlike those used around Richmond, but none of the pits show stony material such as is found in some of the Richmond clay banks.

The most southern of this group of yards is that of C. H. Oliver, which is located one mile west of Fort Lee. The clay here is found immediately underlying the surface and the bank shows 12 feet of clay, although the total thickness of it is said to be 20 feet. Underlying it is a pit of gravel and sand of unknown depth. For making bricks the run of the bank is used. An examination of the clay in the bank shows that the material is mottled in its character, the mottlings consisting of yellow and bluish-white clay, the latter being tougher than the former and unless the material is thoroughly pugged before molding, the bluish white clay shows up in the product in the form of light colored lumps.

The general physical properties of this clay (Lab. No. 1202) are as follows: Color, when moist, yellow buff; water required, 24.2; slaking, moderately fast; plasticity, good; grit, much, fine; air shrinkage, 8.6; average tensile strength, 60.6 pounds per square inch.

In burning it behaved as follows:

WET-MOLDED BRICKLETS.

Cone .....	010	05	03	1	3	5	8
Fire shrinkage .....	0	1.6	4	6.3	7	8.3	7.3
Color.....	lt. red	dk. red	brown				
Absorption.....	20.2	17.6	14.06	7.5	5.9	2.60	1.10

A dry-pressed bricklet burned at cone 1 showed a light red color and a fire shrinkage of 4 per cent.

A chemical analysis of this material is as follows:

Silica ( $\text{SiO}_2$ )	69.55
Alumina ( $\text{Al}_2\text{O}_3$ )	15.79
Iron oxide ( $\text{Fe}_2\text{O}_3$ )	6.05
Lime ( $\text{CaO}$ )	trace
Magnesia ( $\text{MgO}$ )	.08
Potash ( $\text{K}_2\text{O}$ )	1.54
Soda ( $\text{Na}_2\text{O}$ )	.38
Titanic oxide ( $\text{TiO}_2$ )	1.06
Ignition	5.52
	<hr/>
Total fluxes	99.97
	<hr/>
	8.05

This would be classed as a common-brick clay which burns to an excellent light-red color up to 03; a rich red at cone 1, and which vitrifies not far from cone 5. At cone 8 it is beginning to swell, due to the fact that portions of the matrix fuse. These fused parts are evidently small limonite specks which are scattered through the clay. The chemical analysis indicates its siliceous character, and also its red-burning qualities, while the percentage of total fluxes shows that it is not of high refractoriness. In the working of this clay care has to be taken to pug it thoroughly, otherwise the lumps of unpugged clay are apt to cause trouble in the drying and burning of the ware. The sand for the molds is obtained from the foundries, and, on account of its high iron percentage, helps the color of the brick. In the process of brick manufacture at this yard the clay is first put through rolls and passed from there through a soft-mud machine. The bricks are all dried on pallets and the burning is done in Dutch kilns. In the last mentioned stage of the process they get a settle of about 15 inches in 38 courses.

Adjoining Mr. Oliver's yard on the west is that of J. M. Davis. The clay used is similar to that employed at Oliver's pit described above. It is molded by hand; dried on pallets; and burned in Dutch kilns. A few hundred feet up the track and on the north side of it are two yards operated by the Fulton Brick Company. The brick yard adjoins the clay bank on the west and the material is practically the same as that seen at the Davis place, but the methods used for winning the clay are more improved. After the clay is dug it is loaded on to dumping tram-cars and hoisted up to the plant. There it is put through a pair of rolls and passes from these into a Freese side-cut auger machine. While the clay

is not apparently a difficult one to work, still the lumps of bluish gray clay are not thoroughly broken and they show in the finished product. The material is one which also flows very smoothly through the die of the machine.

The clay is taken from the machine to drying tunnels which are steam heated and passes through these in 38 to 40 hours. The burning is done in Dutch kilns. It is quite evident from the results obtained that this clay is not one which will stand rapid drying in the tunnel, for such treatment results in many cracked bricks. In the burning of the ware it was noticed that in several of the kilns the two courses above the arches were nearly vitrified, while the others were by no means so.

The dark-colored clays, similar to those described from south of Chester, outcrop at several points around the base of Government hill, especially along the Government road leading down from the top of the hill, but in nearly every instance they are covered with too much overburden to permit of their being profitably worked.

**SUMMARY.**—It may be well to make a comparative summary of the clays found in the Richmond area. Those found near the city, and those which are worked at Manchester, Fulton, and near the reservoir, are to be classed as good common-brick clays, which burn to a good color, and also make a fair grade of front brick when repressed. They are too gritty and stony as well as too irregular in their character to be used for drain tile, hollow blocks or red earthenware. The methods used for working them are usually crude, and therefore the yards are of limited capacity. The manufacturers claim, however, that owing to difficulties with labor, it is impracticable to use more improved methods, such as machine molding. Some also maintain that the hand-molded brick sells better on the local market.

The clays found at Fort Lee appear to be less stony and even less sandy than those occurring at Richmond, and they are susceptible of being worked by more improved methods. Of the yards located at Fort Lee one used a soft-mud machine, and another a stiff-mud machine. Even these clays, however, are somewhat siliceous for any use other than brick, although it is probable that drain tile or hollow brick could be made from them.

Apparently the best clay in the Richmond area is that described from near Stagg's Mill on the Williamsburg road. This is more plastic, denser burning and less sandy, than any of the clays now being worked either around Richmond or Fort Lee. The deposit being located so close to the city, as well as close to a railroad line should be investigated by clay manufacturers.

Large areas have already been dug over in the brick making districts around Richmond, because the deposits are comparatively shallow, and the output of the yards has been large. Each manufacturer naturally excavates the clay nearest to his yard first, so that as year after year goes by the pit face recedes, and the clay haul becomes longer and longer. As the city of Richmond and its suburbs are growing, it will not be many years before buildings will encroach on the brick yards, and the latter will have to be moved. Being, as it were, temporarily located, there is therefore not much inducement for establishing an extensive plant.

#### THE CURLE'S NECK AREA.

About one mile north of Curle's Neck and 6 miles south of Richmond there are a number of exposures of clay along the road, and also on the farm on the west side of the road at a locality pointed out by Mr. A. W. Ball, of Richmond. This material has been usually spoken of as fullers earth, and some sample car-loads have been shipped to cotton oil factories in order to test it for bleaching purposes. The material, however, is very plastic and on inspection one would be likely to form the opinion that it was a clay suitable for the manufacture of some red-burning ware. In fact it is stated that at one time a small stoneware pottery was in operation at this point and there is considerable evidence of this in the numerous fragments of stoneware which are scattered around in the field near the farmhouse. I was not able to find out, however, just what part of the deposit had been used for making the pots and jugs. In order to determine its value the material was examined both as to its burning qualities and also its bleaching properties. Three samples in all were collected. The first of these (Lab. No. 1314) was a so-called pottery clay taken from about one-half way down the gully just west of the barn on the A. W. Ball property and one mile east of Coltman's postoffice. A second sample ( Lab. No.

1315) was taken from the head of the gully and was said by Mr. Ball to represent the best grade of the fullers earth to be found on this land.

A third sample (Lab. No. 1316) was collected from an outcrop on the west side of the road just southwest of the barn. As regards their bleaching power, it may be said that, while all three bleached the oil moderately well, neither of them is to be classed as a good grade of fullers earth. In fact their bleaching power was inferior to that of some of the earths found in Georgia. They were then tested in order to determine their value for the manufacture of clay products and the results of these tests are given in parallel columns below.

Number	1314	1315	1316
Color.....	yellow buff	yellow buff	light gray
Water required.....	20.9	23.1	24.2
Slaking.....	mody. fast	mody. fast	mody. fast
Plasticity.....	good	good	excellent
Grit.....	little	little	little
Air shrinkage.....	7.4	7.3	8.6
Average tensile strength.....	134.8	126.7	135.1

WET-MOLDED BRICKLETS.

	1314	1315	1316
<i>Cone 010</i>			
Fire shrinkage.....	0	0	0
Color.....	light red	light red	pink cream
Absorption.....	17.7	19.5	16.03
<i>Cone 05</i>			
Fire shrinkage.....	4.7	3	4.3
Color.....	light red	light red	pink buff
Absorption.....	10.1	14.8	9.2
<i>Cone 03</i>			
Fire shrinkage.....	6	4.3	5
Color.....	light red	light red	buff
Absorption.....	7.02	13.1	4.7
<i>Cone 1</i>			
Fire shrinkage.....	8.3	9	6.5
Color.....	red	red	gray buff
Absorption.....	1.5	2.5	.09
<i>Cone 3</i>			
Fire shrinkage.....	7.6	8.6	7
Color.....	dark red	dark red	gray buff
Absorption.....	.4	1.01	.07
<i>Cone 5</i>			
Fire shrinkage.....	beyond vitri.	7	7
Color.....		gray	drab
Absorption.....		.70	.14
<i>Cone 8</i>			
Fire shrinkage.....		7	beyond vit.
Color.....		dk. red brown	
Absorption.....		.55	9

## DRY-PRESS BRICKLETS

<i>Cone 1</i>		
Fire shrinkage.....	7	8
Color.....	light red	light red
<i>Cone 3</i>		
Fire shrinkage.....		8
Color.....		dark brown
Absorption.....		5.93

Chemical analyses of samples of these earths yielded the following results:

Lab. No.	1314	1315	1316
Silica (SiO <sub>2</sub> ) . . . . .	65.97	63.82	66.01
Alumina (Al <sub>2</sub> O <sub>3</sub> ) . . . . .	17.38	20.44	20.77
Ferric oxide (Fe <sub>2</sub> O <sub>3</sub> ) . . . . .	6.74	6.32	3.59
Lime (CaO) . . . . .	1.16	.22	.92
Magnesia (MgO) . . . . .	.17	.11	.11
Potash (K <sub>2</sub> O) . . . . .	2.46	2.72	2.52
Soda (Na <sub>2</sub> O) . . . . .	.93	.93	.74
Titanic oxide (TiO <sub>2</sub> ) . . . . .	1.04	tr.	.50
Loss on ignition . . . . .	4.10	5.41	4.82
	99.95	99.97	99.98
Total fluxes . . . . .	11.46	10.30	7.88

Number 1314, the so-called pottery clay, is a red-burning clay of good plasticity which becomes steel-hard at cone 05. The color does not deepen appreciably until cone 1, at which temperature it makes a pretty dense body and is almost vitrified. At cone 3 the body is also dense but the clay is beyond vitrification, while at cone 8 it has reached the beginning of viscosity. The qualities shown by this clay would seem to warrant its being tested on a larger scale for the manufacture of paving brick or perhaps even common stoneware.

Number 1315. This clay is very similar in appearance to No. 1314 and becomes steel-hard at cone 05. It burns red but the color deepens appreciably at cone 1 and the clay does not appear to be really vitrified until cone 3. The chances are that it might serve for making paving brick for light traffic and perhaps even common stoneware.

Number 1316 burns steel-hard at cone 05, and gives an excellent buff color at that cone. In fact at that temperature it would do for buff pressed brick but even if heated above that cone the color is not at all unpleasing. It appears to be vitrified at cone 5 and at cone 8 is very close to viscosity. Its lighter burning character is due to the smaller percentage of iron oxide which it contains.

CHESTERFIELD COUNTY.

THE CHESTER AREA.

There are no brick yards in operation at this locality, but a number of outcrops of clay are to be seen in the railroad and trolley road cuts in the vicinity. None of them, however, are suited to the manufacture of brick. About two miles south of Chester along the Atlantic Coast-Line Railway there are several cuts, which show outcrops of a sandy, bluish, fossiliferous clay. The material is not uniform in character, certain layers being highly fossiliferous, others very sandy, and still others very plastic. The exact thickness of the deposit is not known, but from the exposures it is evidently not less than thirty feet thick. No attempts have been made to utilize it. Since there is a large amount of the clay at this locality, and the same material is found outcropping around Richmond, it was thought desirable to look into its properties. These were as follows: The color of the moist clay (Lab. No. 1305) is gray black, indicating a considerable quantity of organic matter. It slakes fast, and worked up with 25.3 per cent. water to a somewhat gritty mass of low plasticity, whose air shrinkage was 9.3 per cent., and whose average tensile strength was 177.3 pounds per square inch. In burning it behaved as follows:

WET-MOLDED BRICKLETS.

Cone .....	010	05	03	1	3
Fire shrinkage	0	1.3	1.6	2.3	viscous
Color .....	light red	light red	red	red	
Absorption .....	18.2	14.2	12	7.54	

The material does not burn steel-hard until cone 1, and has to be carefully burned to prevent black cores forming.

Its chemical composition was as follows:

Silica (SiO <sub>2</sub> )	69.74
Alumina (Al <sub>2</sub> O <sub>3</sub> )	12.64
Ferric oxide (Fe <sub>2</sub> O <sub>3</sub> )	6.00
Ferrous oxide (FeO)	1.00
Lime (CaO)	1.46
Magnesia (MgO)	1.18
Potash (K <sub>2</sub> O)	2.54
Soda (Na <sub>2</sub> O)	.92
Titanic oxide (TiO <sub>2</sub> )	.06
Water and organic matter	4.41
	99.55
Total fluxes	13.10

The general characteristics of the clay may therefore be summed up as follows: Red burning, low fire shrinkage, and low fusibility. Difficult to burn. It is not to be recommended for anything but common brick, and even for this purpose it should be avoided if something better can be found.

THE BERMUDA HUNDRED AREA.

Much clay is exposed at a point along the railroad from Chester to Bermuda Hundred and about 1 mile from the railroad station at the latter locality. The same material is also seen in the gullies in the neighboring fields. This clay is at the same level as that which is worked at Broadway on the Appomattox and it is probable that the deposit extends in that direction, but they do not belong to the same formation.

The exposures in the railroad cut show a thickness of not less than ten feet, and Mr. Strothers, of Chester, claims that a thickness of 49 feet was proved by boring in one place. Although the clay along the railroad track does not show much variation on inspection, it is stated that at the northeastern end is brick clay, while at the southeastern end it is tile clay. A sample of the latter (Lab. No. 1306) was tested with the following results: Color, yellow buff; slaking, fast; water required, 29.7 per cent.; plasticity, good; grit, very fine; air shrinkage, 8.6 per cent.; average tensile strength, 148.8 pounds per square inch. In burning it behaved as follows:

WET-MOLDED BRICKLETS.

Cone .....	010	05	03	1	3	5	8
Fire shrinkage .....	.3	5.7	7	10.7	10.3	4.6	6.6
Color .....	lt. red	lt. red	lt. red	dk. red	dk. red	dk. red	dk. red
Absorption.....	22.04	12.9	8.7	.12	.11	2.1	1.39

DRY-PRESS BRICKLETS.

Cone .....	1	3
Fire shrinkage .....	9	9
Color .....	lt. red	lt. red
Absorption .....		6.8

The clay burned steel-hard at cone 03. It burned to a good red up to cone 03 but above this began to darken appreciably, and at cone 5 had gotten beyond vitrification.

The chemical composition was:

Silica (SiO <sub>2</sub> )	61.83
Alumina (Al <sub>2</sub> O <sub>3</sub> )	21.26
Iron oxide (Fe <sub>2</sub> O <sub>3</sub> )	6.85
Lime (CaO)	.38
Magnesia (MgO)	.78
Potash (K <sub>2</sub> O)	2.44
Soda (Na <sub>2</sub> O)	1.01
Titanic oxide (TiO <sub>2</sub> )	.08
Ignition	5.32
	<b>99.95</b>
Total fluxes	11.46

Judging from the dense body of this material it would be worth experimenting with for paving brick, or perhaps pipe. The most serious objection to it is its high air and fire shrinkage.

This clay has been dug and shipped, occasionally, to the works of the Powhatan Clay Manufacturing Company, at Clayville, near Richmond.

DINWIDDIE COUNTY.

THE PETERSBURG AREA.

There are three yards in operation near Petersburg. Two of these, operated, respectively, by W. R. Turner, and Brister and Harrison, are located in Ettricks, across the river from Petersburg; the third, that of the Chesterfield Brick Company, is situated about two miles from Petersburg near the line of the Petersburg-Richmond trolley road.

At the yard of W. R. Turner, the clay (Pl. XIII, Fig. 2.) which is covered by a foot of sand, runs from 15 to 20 feet deep. It is mottled, red, yellow, brown and whitish, and there is also some variation in the other physical properties of the clay. It is therefore necessary to use the run of the bank, as one part, if used alone, laminates too much, or another portion, if used alone, is too sandy, etc. The clay is underlain by sand.

The properties of the run of the bank (Lab. No. 1331) were as follows: Color, when moist, brown buff; water required, 23.1; slaking, slow; plasticity, excellent; grit, little; air shrinkage, 8 per cent.; average tensile strength, 135.5 pounds per square inch.

In burning it behaved as follows:

WET-MOLDED BRICKLETS.

	010	05	03	1	3	5	8
Fire shrinkage.....	.3	2	3.6	4.6	5	7.6	6.3
Color.....	lt. red	lt. red	lt. red	red	red	dk. red	dk. red
Absorption.....	17.09	15.30	11.80	7.8	8.7	3	1.3

## DRY-PRESS BRICKLETS.

Cone.....	1	3
Fire shrinkage.....	4	4
Color.....	lt. red	lt. red
Absorption.....		11.78

The chemical analysis showed:

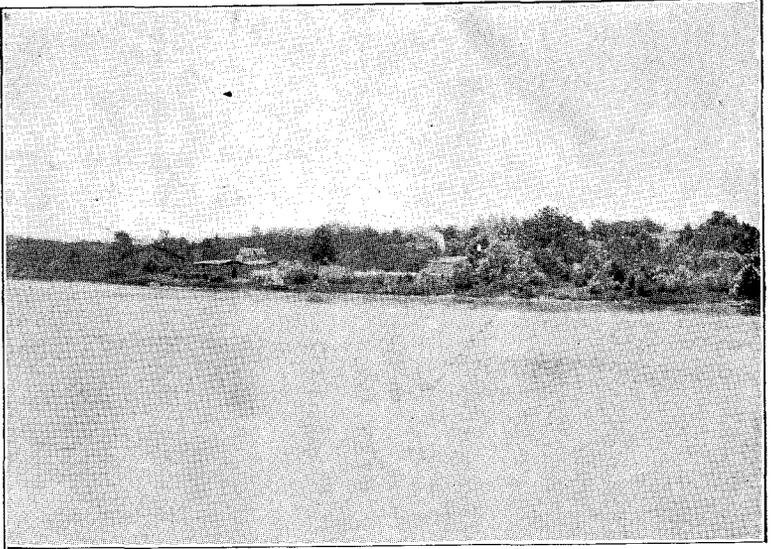
Silica (SiO <sub>2</sub> ) .....	61.35
Alumina (Al <sub>2</sub> O <sub>3</sub> ) .....	19.70
Ferric oxide (Fe <sub>2</sub> O <sub>3</sub> ) .....	7.10
Lime (CaO) .....	.67
Magnesia (MgO) .....	.34
Potash (K <sub>2</sub> O) .....	2.38
Soda (Na <sub>2</sub> O) .....	1.11
Titanic oxide (TiO <sub>2</sub> ) .....	.06
Ignition .....	7.25
	<hr/>
	99.96
Total fluxes .....	11.60

This clay burns to an excellent red color which is rather light up to cone 03, but at cone 1 is much richer, and if burned for front brick at this cone would probably yield an excellent product. The clay burns steel-hard at cone 1, and vitrifies a little above cone 5. At cone 8 it was not yet viscous. The air shrinkage is somewhat higher than is desirable, but this can be regulated by using a larger proportion of the sandy clay. The clay would no doubt work for dry-press brick and if hard burned might even serve for paving purposes under light traffic.

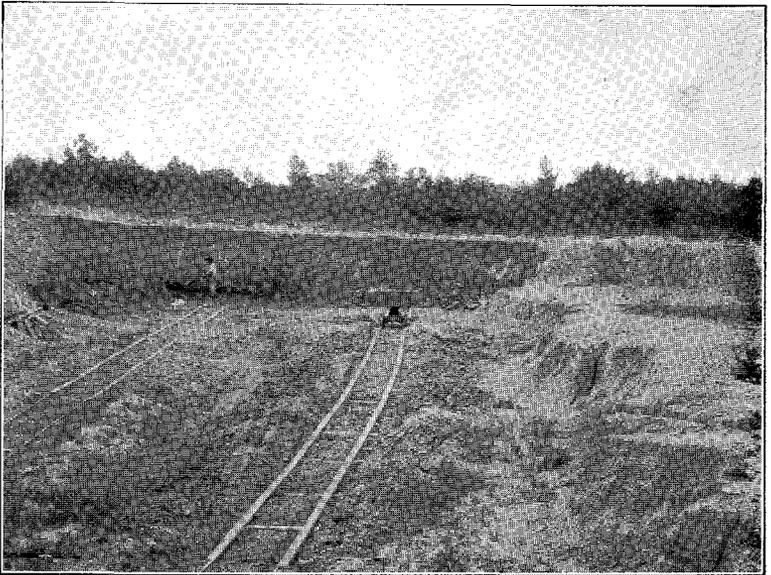
At present it is used only for common building brick. The run of the bank is tempered in a pugmill, and molded in an auger side cut machine. (Pl. VII.). The bricks are dried under sheds, and the burning done in Dutch kilns. Some repressing is done in a hand-power machine.

Brister and Harrison's yard adjoins Turner's on the east, and the clay deposits at the two yards are undoubtedly continuous. The overburden is not more than one foot thick and the clay varies from 10 to 20 feet in thickness, resting on an uneven bottom of sand and gravel. As the clay in this bank varies much like that in the preceding, it is equally important to mix it. If properly mixed and pugged it works well on a stiff-mud machine.

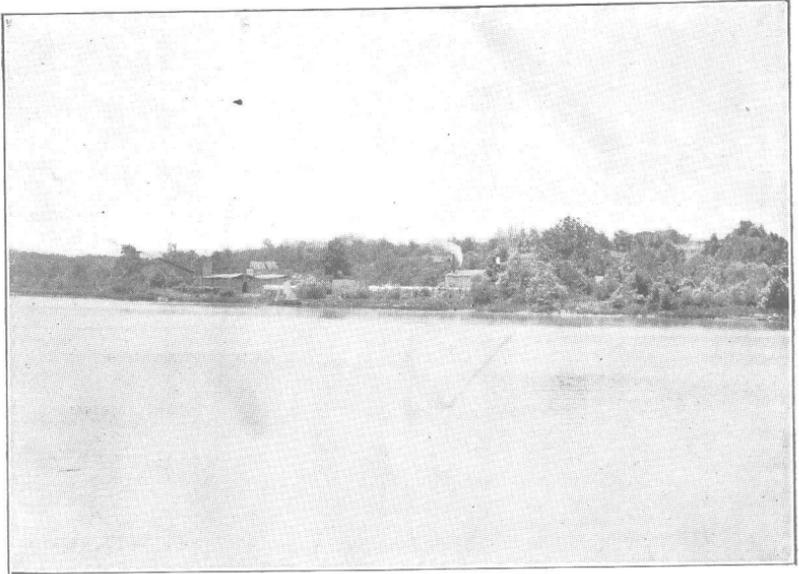
The clay is molded on a plunger stiff-mud machine, dried on pallets and burned in scove kilns.



A. General view of Keeler's brick yard at Broadway on the Appomattox River.  
The clay bank lies at top of bluff to rear of yard.



B. Keeler's clay bank at Broadway on the Appomattox River.



A. General view of Keeler's brick yard at Broadway on the Appomattox River.  
The clay bank lies at top of bluff to rear of yard.



B. Keeler's clay bank at Broadway on the Appomattox River.

The type of clay used at Turner's, and Brister and Harrison's yards is not an uncommon one around Petersburg, and a number of exposures of it are to be found, especially in the cuts along the Seaboard Air-Line Railway, but much of the area around the city is underlain by a heavy bed of sand and gravel.

At the works of the Chesterfield Brick Company, whose location is mentioned above, the material used is a sandy surface loam, of a type not uncommon in this vicinity, and which is perhaps of residual character, having been derived from the underlying granites. The clay is very shallow and suitable only for common brick. At present it is being worked by the stiff-mud process, but the company is abandoning the use of this clay, and intends working a more plastic material which will give better results.

The local contractors state that the supply of bricks from the yards around Petersburg is entirely insufficient to meet the demand in that city.

---

#### PRINCE GEORGE COUNTY.

##### THE BROADWAY AREA.

The only brick yard in operation at this locality is that of Keeler & Son, which is located immediately at the foot of the bluff along the Appomattox river. The clay deposit lies about 75 feet above the river and the clay is being dug at a point in the terrace about 300 feet south of the yard. It is a tough, mottled material with a thickness of at least 15 feet, the upper two feet of which are weathered. Overlying this is about 18 inches of gravelly sand similar to that which occurs immediately under the surface throughout this region on both sides of the river. The clay is underlain by a coarse, gravelly sand which extends down to the river level and probably below it. The pit, however, is not over 7 feet deep (Pl. XI, Fig. 2.). The physical and chemical properties of the clay (Lab. No. 1307) are as follows: Color, moist, yellow buff; slaking, slow; water required, 24.6; plasticity, good; grit, not excessive; air shrinkage, 9 per cent.; average tensile strength, 138.1 pounds per square inch. In burning the clay behaved as follows:

## WET-MOLDED BRICKLETS

Cone .....	010	05	03	1	3	5	8
Fire shrinkage .....	.3	5	6.3	8	9.3	7	7.6
Color .....	lt. red	lt. red	lt. red	red	dk. red	red. gr.	red br.
Absorption ..	17.9	10.40	7.3	1.7	.8	1.7	.50

## DRY-PRESS BRICKLETS.

Cone .....	1	3
Fire shrinkage .....	8	8
Color .....	red	red
Absorption .....		10.17

The clay burns steel-hard at cone 05 and at either this temperature or cone 03 it makes an excellent red brick. I doubt, however, if even cone 05 is reached in burning the product. If burned to this cone, or, better still, to cone 1, the material would probably make a good pressed brick.

The chemical composition is:

Silica (SiO <sub>2</sub> ) ..	59.59
Alumina (Al <sub>2</sub> O <sub>3</sub> ) ..	21.10
Ferric oxide (Fe <sub>2</sub> O <sub>3</sub> ) ..	8.07
Lime (CaO) ..	.20
Magnesia (MgO) ..	.76
Potash, (K <sub>2</sub> O) ..	2.38
Soda (Na <sub>2</sub> O) ..	1.06
Titanic oxide (TiO <sub>2</sub> ) ..	.12
Loss on ignition ..	6.67
	99.95
Total fluxes ..	12.47

This is an excellent red-burning clay which could probably be used for making front as well as common brick, provided it is thoroughly pugged. Although it burns to a good hard body, still, at the same temperatures, the product is not as dense as that tested from near Bermuda Hundred (Lab. No. 1306) or that tested from 6 miles south of Richmond (Lab. Nos. 1314 and 1316). At the present time it is utilized for making common brick and the run of the bank is used, leaving out the overburden of gravelly sand. The clay is loaded onto tram-cars, drawn to the edge of the terrace, and then slid down a chute to the rolls. From these it passes to a side-cut stiff-mud machine. The clay, owing to its good plasticity, seems to flow very rapidly from the die. Drying is done by what is known as the Scott system. This consists in loading the freshly molded brick onto cars, the platform of which is separate from the trucks. These cars are run in under long drying

sheds similar to those shown in Pl. XI, Fig. I., and the platforms carrying the bricks are deposited on separate racks. In order to prevent the clay from drying too fast and cracking, the sides of the racks are protected from the wind by canvas curtains. The bricks are burned in Dutch kilns and the product is shipped by boat, most of it going to Petersburg.

#### THE CITY POINT AREA.

The Pleistocene clays outcrop in the bluff along the James river, about 1-8 mile south of City Point landing. Their distribution is evidently irregular, for in the first cut of the railroad after leaving City Point, there is nothing but sand exposed, although the bottom of the cut is not as high as the upper part of the clay along the river shore. I was informed that borings made to the south of the railroad cut had revealed the presence of the clay under the surface sand. Along the shore the clay is not less than 20 feet thick, but it contains occasional streaks of sand. There is also about four feet of sandy overburden. No brickyard is located at this point, although the deposit is at the water's edge and the product could be easily shipped. Occasional car-load lots have, however, been dug and shipped to the smoking pipe factory at Pamplin City. As for this line of ware, a small quantity of clay will go a long way, as the amount that has been dug has produced but little impression.

The characters of the clay (Lab. No.1339) are as follows: Color, when moist, brown buff; water required, 20.3 per cent.; slaking, slow; plasticity, excellent; grit, much; air shrinkage, 7.6 per cent.; average tensile strength, 155 pounds per square inch. In burning it behaved as follows:

#### WET-MOLDED BRICKLETS.

<i>Cone</i> .....	010	05	03	1	3	5	8
Fire shrinkage... ..	.6	3.3	4	6	6.3	6.6	6.6
Color.....	lt. red	lt. red	lt. red	red	dk. red	dk. red	dk. red
Absorption.....	17.2	11.5	10.05	4.6	2.7	1.3	1.52

The chemical composition of this clay is shown in the following analysis:

Silica ( $\text{SiO}_2$ )	61.06
Alumina ( $\text{Al}_2\text{O}_3$ )	19.61
Ferric oxide ( $\text{Fe}_2\text{O}_3$ )	7.03
Lime ( $\text{CaO}$ )	.77
Magnesia ( $\text{MgO}$ )	.09
Potash ( $\text{K}_2\text{O}$ )	2.34
Soda ( $\text{Na}_2\text{O}$ )	1.01
Titanic oxide ( $\text{TiO}_2$ )	.16
Ignition	7.76
Total fluxes	99.83
	11.24

This clay burns steel-hard at cone 05, and yields an excellent red color which it maintains up to cone 03, but above that the color deepens appreciably. It is not as fine grained a clay as that found in the same formation near Bermuda Hundred, nor is it as sandy as that at Broadway. The main advantage of it is, that it is conveniently located for shipment by rail, an advantage not possessed by most deposits along the James river.

CHARLES CITY COUNTY.  
THE SURGEON POINT AREA.

W. C. Mayo & Sons operate a common-brick yard at this locality. The plant is located along the river edge at the base of the bluff, while the clay is obtained from near the top of the bluff. The section at this point involves:

Loam	1 to 2 ft.
Clay	.7 to 8 ft.
Sand	2 ft.
Mottled clay with iron streaks	.9 ft.
Sand	20 to 30 ft.
Blue Clay	3 ft.+

The sand mentioned in the lower part of the section extends down to the river's edge, and at that point it is underlain by a bed of dark bluish gray, highly plastic clay which is about three feet in thickness. The upper layer of clay was formerly worked and a considerable quantity of it has been dug. It was found, however, that it was so variable in its character and burning qualities that it was undesirable to use it, and consequently the raw material for the yard is now taken from the middle clay bed given in the section which yields a more uniform product. The variation in character of the upper clay has been referred to and the tests given. The properties of the lower clay (Lab. No. 1311) are as follows:

Color, yellow buff; water required, 23.1; slaking, moderately fast; plasticity, good; grit, mostly fine; air shrinkage, 7.6 per cent.; average tensile strength, 122.6 pounds per square inch.

In burning the material behaved as follows:

WET-MOLDED BRICKLETS.

Cone .....	010	05	03	1	3	5	8
Fire shrinkage .....	0	2.3	3	5.6	7	5.3	5.6
Color.....	lt. red	lt. red	red	red	dk. red	dk. red	dk. red
Absorption.....	16.8	11.9	8.2	3.9	1.9	1.5	1.07

DRY-PRESS BRICKLETS.

Cone .....	1
Fire shrinkage .....	3
Color .....	lt. red

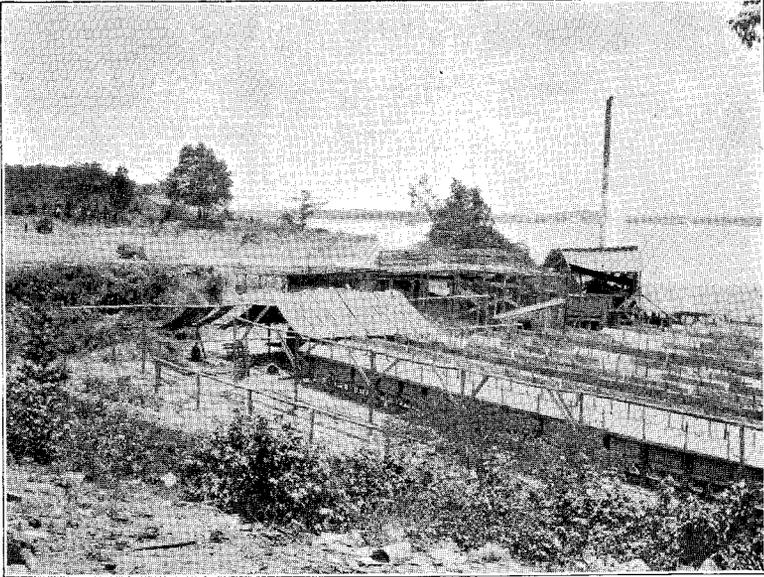
The chemical composition of the material was:

Silica (SiO <sub>2</sub> ) .....	68.60
Alumina (Al <sub>2</sub> O <sub>3</sub> ) .....	16.11
Iron oxide ((Fe <sub>2</sub> O <sub>3</sub> ) .....	6.41
Lime (CaO) .....	.75
Magnesia (MgO) .....	.32
Potash (K <sub>2</sub> O) .....	2.35
Soda (Na <sub>2</sub> O) .....	.71
Titanic oxide (TiO <sub>2</sub> ) .....	.16
Loss on ignition .....	4.53
	99.94
Total fluxes .....	10.54

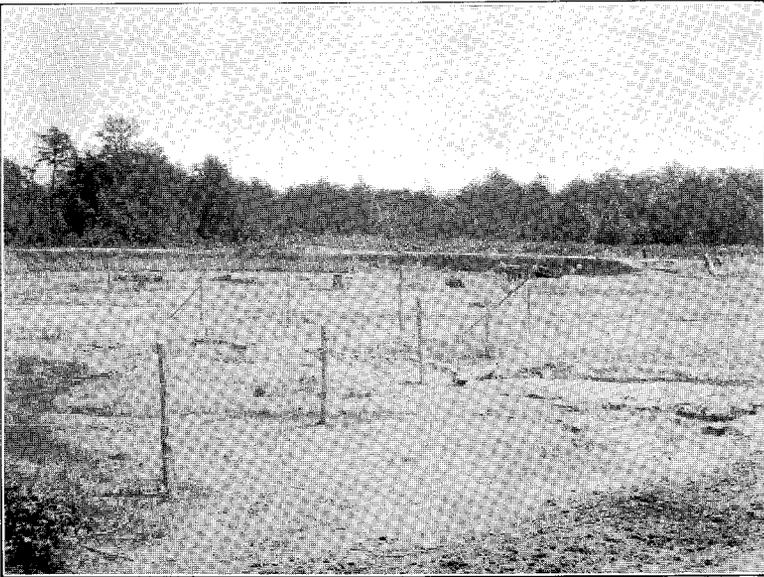
This clay which becomes steel-hard at cone 05 burns to a rather light red up to cone 03, but at cone 1 it yields a very rich red. It appears to vitrify at a rather low temperature, namely, cone 3, and yet on account of the fine grit it contains, it does not give as dense a body as some of the other clays tested from this formation. At cone 8 it was almost viscous. It is claimed that this deposit of clay extends more or less continuously for at least 12 miles back from the river. In making the clay into brick the run of the bank is used. The material is put through a pugmill and molded in an end-cut auger machine. The bricks are dried in a steam drier, this operation taking about 36 hours. The burning is done in Dutch kilns, and there is said to be 10 inches settle in 46 courses.

The bluish gray clay which outcrops along the river's edge is not more than 3 feet thick and it would probably be difficult to mine, but since the bed is quite persistent and there is a possibility of its outcropping at other points, it was deemed advisable to test a sample of it which was done with the following results:

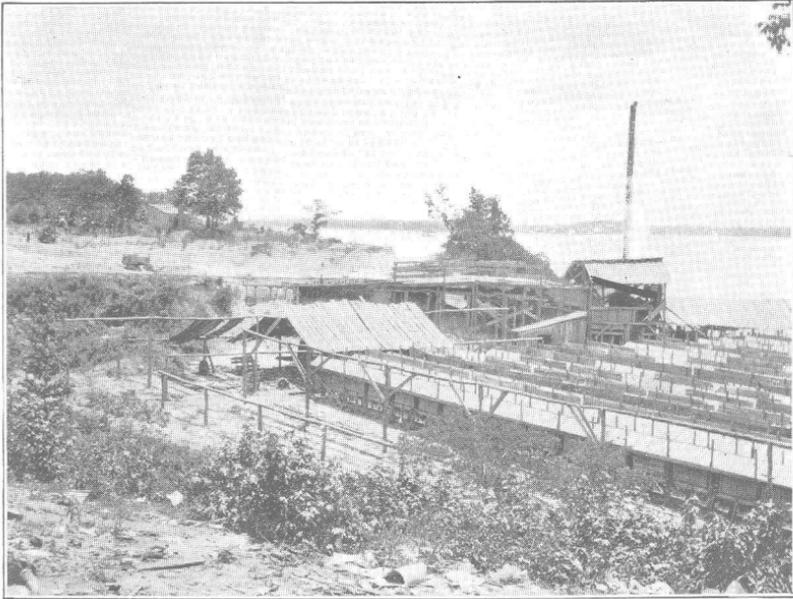




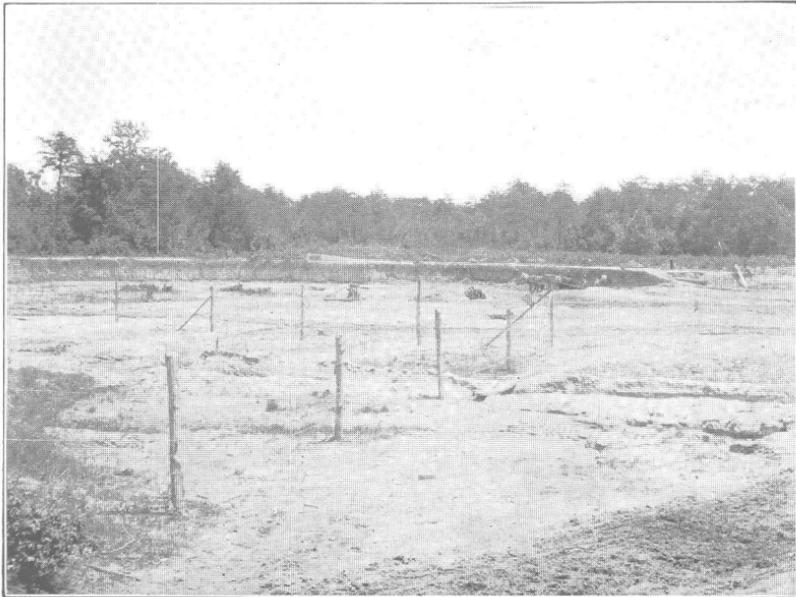
A. General view of Oldfield Brick Co.'s Plant, Oldfield, on James River.  
Clay pit at rear of yard.



B. Clay pit of Oldfield Brick Co. The clay underlies terrace bordering river.



A. General view of Oldfield Brick Co.'s Plant, Oldfield, on James River.  
Clay pit at rear of yard.



B. Clay pit of Oldfield Brick Co. The clay underlies terrace bordering river.

by a siliceous clay, which weathers to a whitish color and contains many cylindrical limonite concretions. The upper bed has an average thickness of about 3 feet, and this is first removed and utilized for the manufacture of common brick. The under bed seems to be variable in its thickness but where best exposed at the south side of the deposit and nearest to the yard the thickness is at least 7 feet. It is underlain by a tough sandy clay which is not used and which passes downward into a bed of loamy sand containing streaks of pebbles. The two kinds of clay are worked separately, the upper clay being used for common brick, and the lower clay, with the limonite concretions, known as the tile clay, being used for tile or extra hard brick termed paving brick. A sample of each of these was tested and the tests of the two are given in parallel columns, No. 1 being the brick clay, and No. 2 the so-called tile clay.

Lab. No.	1313	1312
Color.....	buff	gray
Water required.....	23.1	20.3
Slaking.....	mody. fast	slow
Plasticity.....	good	good
Grit.....	little	much
Air shrinkage.....	8.6	7.6
Average tensile strength.....	191	111.5
<i>Cone 010</i>		
Fire shrinkage.....	.3	0
Color.....	light red	pink buff
Absorption.....	17.5	16.3
<i>Cone 05</i>		
Fire shrinkage.....	1.6	1.6
Color.....	light red	pink buff
Absorption.....	14.8	15.04
<i>Cone 03</i>		
Fire shrinkage.....	4	2
Color.....	light red	pink buff
Absorption.....	9.6	13.6
<i>Cone 1</i>		
Fire shrinkage.....	6.3	3.6
Color.....	red	yellow red
Absorption.....	5.5	7.2
<i>Cone 3</i>		
Fire shrinkage.....	7	6
Color.....	red	pink buff
Absorption.....	4.9	3.9
<i>Cone 5</i>		
Fire shrinkage.....	7.6	6.6
Color.....	dark green	gray
Absorption.....	1.68	1.08
<i>Cone 8</i>		
Fire shrinkage.....	5	7.3
Color.....	drab	drab
Absorption.....	1.10	1.57

## DRY-PRESS BRICKLETS

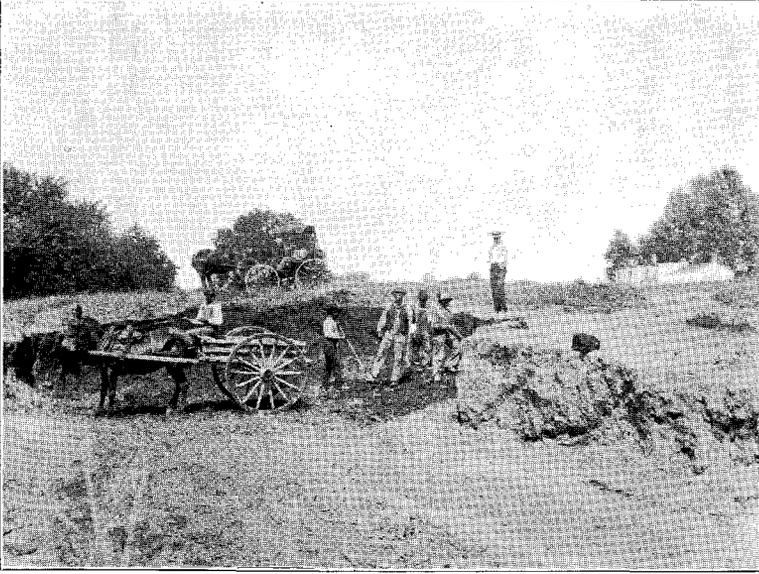
<i>Cone 1</i>		
Fire shrinkage.....	4	3
Color .....	light red	gray buff
Absorption.....		
<i>Cone 3</i>		
Fire shrinkage.....		3
Color.....		light pink
Absorption.....		15 14

A chemical analysis made of each of these clays yielded the following results:

	1313	1312
Silica (SiO <sub>2</sub> ).....	68.97	73.84
Alumina (Al <sub>2</sub> O <sub>3</sub> ).....	16.51	15.08
Ferric oxide (Fe <sub>2</sub> O <sub>3</sub> ).....	4.22	3.39
Lime (CaO).....	.44	.62
Magnesia (MgO).....	.05	.12
Potash (K <sub>2</sub> O).....	2.59	2.17
Soda (Na <sub>2</sub> O).....	.56	.71
Titanic oxide (TiO <sub>2</sub> ).....	1.23	1.22
Loss on ignition.....	5.34	2.81
	99.96	99.96
Total fluxes .....	7.86	7.01

No. 1313 at low temperatures is a rather light-burning brick clay which becomes steel-hard at cone 03. The color does not deepen appreciably up to cone 1. In order to get a good, hard brick it should be burned at cone 05. The clay seems to vitrify about cone 5, giving a good hard body, but at cone 8 it is past vitrification. At cone 5 the body is very dense and appears much like a stoneware body. Its air shrinkage is a little high and its total shrinkage at cone 5 is not any too low.

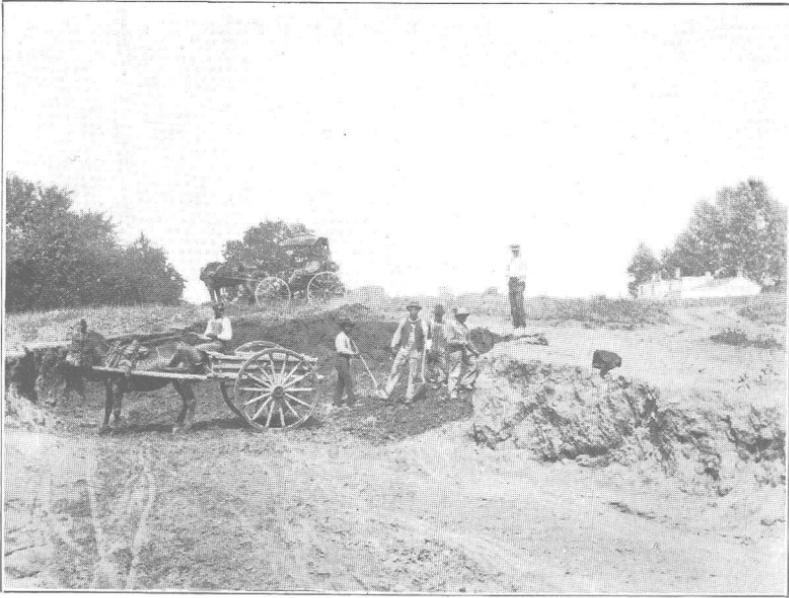
Number 1312 is a much more sandy clay which does not burn steel-hard until cone 1, and appears to vitrify at cone 8. At that temperature it burned to a very hard dense body, but one which was not as dense as the Bermuda Hundred clay when burned at cone 3. The difference in the sandiness of the clays is brought out quite well by a comparison of the chemical analyses, No. 1312 having much the higher silica percentage. The chemical composition also indicates the red-burning character of the clay, and No. 1312 burns to a lighter color, not because it contains much less iron than No. 1313 but because the iron is not evenly distributed



A. Ferruginous sandy clay; a type not uncommon around Petersburg. Used for common brick making, but of greater value as a molding sand.



B. General view of Turner's clay pit, Ettricks, near Petersburg. There is practically no overburden.



A. Ferruginous sandy clay; a type not uncommon around Petersburg. Used for common brick making, but of greater value as a molding sand.



B. General view of Turner's clay pit, Ettricks, near Petersburg. There is practically no overburden.

through the clay; it being present rather in spots. Of these two clays No. 1313 is by far the more preferable for the production of a hard, dense product.

At present the product of the yard consists almost entirely of common brick for which the run of the bank is used. The clay is hauled in cars to the edge of the terrace and dumped into rolls from which it passes into a Chambers end-cut auger machine with a revolving cut off (Pls. V. and VI.). The green bricks are loaded onto cars which are run onto the drying racks where the platform of the cars is left, the Scott system of drying being used. The product is burned in Dutch kilns and most of it is shipped to Norfolk.

GREENESVILLE COUNTY.

THE BELFIELD AREA.

This town, which adjoins the better known one of Emporia, has one yard, whose product consists entirely of common brick, and which is operated by Dr. Wood, of Emporia. The soil is quite sandy around Belfield, and the surface flat, so that there are very few clay exposures. At the brick yard the clay extends nearly to the surface and averages about 5 feet deep, being bottomed on a coarse, whitish sand, which is not mixed in with the clay as it does not seem to improve its quality. The clay (Lab. No. 1333) is a tough brownish material, with comparatively little sand, but much fine grit. It slakes slowly and works up with 24 per cent. of water to a mass of good plasticity, whose air shrinkage was 8.6 per cent. and whose average tensile strength was 132.4 pounds per square inch.

In burning it behaved as follows:

WET-MOLDED BRICKLETS

<i>Cone</i> .....	010	05	03	1	3	5	8
Fire shrinkage.....	.3	1	2.7	3	3.6	4.3	6
Color.....	lt. red	lt. red	lt. red	red	dk. red	dk. red	dk. red
Absorption.....	16.30	13.70	11.90	11.05	9.9	6.20	1.08

DRY-PRESS BRICKLETS.

<i>Cone</i> .....	1	3
Fire shrinkage.....	2	2
Color.....	red	red
Absorption.....		17.25

A chemical analysis of this clay gave:

Silica ( $\text{SiO}_2$ )	67.14
Alumina ( $\text{Al}_2\text{O}_3$ )	16.18
Ferric oxide ( $\text{Fe}_2\text{O}_3$ )	6.21
Lime ( $\text{CaO}$ )	1.19
Magnesia ( $\text{MgO}$ )	.11
Potash ( $\text{K}_2\text{O}$ )	1.95
Soda ( $\text{Na}_2\text{O}$ )	1.10
Titanic oxide ( $\text{TiO}_2$ )	
Ignition	6.09
	<hr/>
Total fluxes	99.97
	<hr/>
	10.56

The clay burns to an excellent red color, but contains so much fine grit that even at cone 3 it does not yield a dense brick; indeed it does not show a very low absorption until cone 8, at which point it begins to fuse. It is not to be recommended for anything but common brick.

The clay as it comes from the bank is put through a pug-mill, from which it is fed directly through the die of an auger machine, so that the material does not receive enough pugging. The bricks are piled on cars, which are run onto racks for drying. Sun drying causes the clay to crack. Burning is done in Dutch kilns.

#### NORFOLK COUNTY.

##### THE NORFOLK AREA AND VICINITY.

The cities of Norfolk, Portsmouth and Newport News are among the most important in the Coastal Plain area of Virginia, and in all building operations are being carried on quite extensively. There is here consequently a good market for building brick, either common or pressed, and the supply is drawn from a number of points.

There are several yards in the immediate vicinity of these cities which deserve mention. E. W. Face and Son operate a yard on North Avenue, Atlantic City. The raw material is brought from a pit of Pleistocene clay on the Nansemond river, near Suffolk, and in its general character resembles that worked at the brick yards around Suffolk. It is a red-burning clay of excellent plasticity, which yields a good product for structural work. Before molding the clay has a small quantity of fine coal mixed in with it, to help in burning, a practice somewhat unusual in the Coastal Plain area. It is molded on an end-cut auger machine, dried on hot floors,

and burned in up-draft kilns with permanent side walls. The drying takes 48 hours and the burning from eight to ten days. Some repressing is also done. The entire product is disposed of in Norfolk.

The plant of the Builders Supply Company is located on Middle street, Chesterfield Heights. The clay is a light-colored sandy material averaging about 3 1-2 feet in thickness. There are only a few inches of soil over it, and the clay is free from stones or shells.

The brick are molded in an end-cut auger machine, dried in the sun and burned in Dutch kilns. No repressing is done. The product is of a red color and sells on the local market.

G. A. Stephens' brick yard is located on the Princess Anne road near Godfrey Avenue. It is also working a surface clay, which, however, is somewhat different in its appearance from that at the preceding plant. The clay which immediately underlies the soil is a bluish black, very stiff red-burning clay. On account of its plasticity it is necessary to mix some sand with it to make it more easy working as well as to reduce its plasticity. The clay is molded in soft-mud machines, air dried, and burned in up-draft kilns. The product is sold for common brick.

C. H. Phillips and Brothers operate a yard at Hampton, near Newport News, and here a reddish, sandy, surface clay is used, for making common soft-mud brick.

At Morrison, 1 mile north of the station, is the yard of the Booker Brick Company, whose product goes mostly to Norfolk. This is a shallow Pleistocene deposit, 3 or 4 feet in depth and underlain by sand. The material is red-burning and used only for the manufacture of common brick. Its chemical composition is:

Silica (SiO <sub>2</sub> )	68.84
Alumina (Al <sub>2</sub> O <sub>3</sub> )	14.78
Ferric oxide (Fe <sub>2</sub> O <sub>3</sub> )	3.08
Lime (CaO)	.12
Magnesia (MgO)	.08
Potash (K <sub>2</sub> O)	2.32
Soda (Na <sub>2</sub> O)	.83
Titanic oxide (TiO <sub>2</sub> )	.78
Moisture 110° C.	3.90
Ignition	5.44
	<hr/>
Total fluxes	100.17
	<hr/>
	6.43

## NANSEMOND COUNTY.

## THE SUFFOLK AREA.

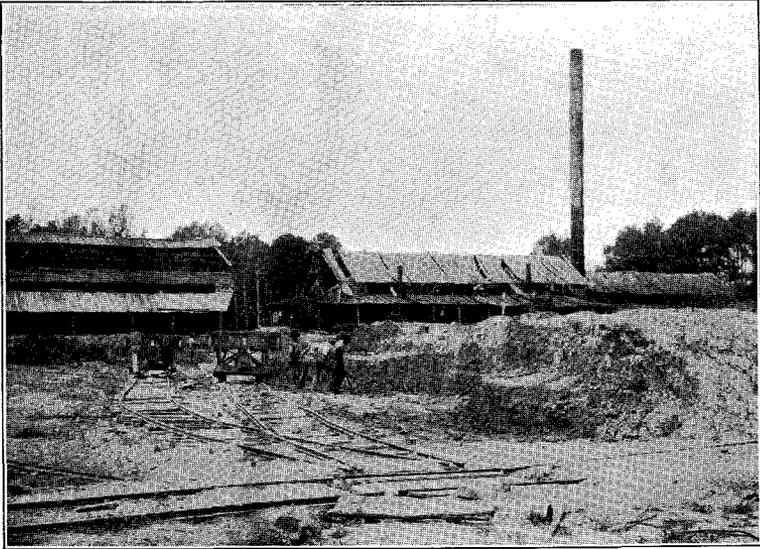
Four brick yards were visited at this locality, namely, those of the Standard Brick Company, Horrell and Company, Suffolk Clay Company, and West End Company.

The Standard Brick Company's yard is located about one and a half miles south of Suffolk along the Southern Railway. The surrounding region is underlain by a deposit of sand, often of coarse grain and variable thickness. Some of it might serve for molding sand, and much of it no doubt would answer for the manufacture of sand-lime brick. If the region between Suffolk and the brick works is underlain by clay it could only be determined by boring or test-pits. At the pit of the Standard Brick Company (Pl. XIV, Fig. 1.) there is a little stripping to be done before the clay is reached. The bed has a depth of about 6 feet, the lower two to three feet being a dark bluish gray and the upper half discolored by weathering. At the time of the writer's visit only the lower clay was being used. This burns to a harder brick but has a higher shrinkage than the top clay. The material is loaded onto cars and hoisted up an incline to the works. Then it passes through a pair of rolls to the pugmill which tempers it for the end-cut auger machine. The clay runs through the die with remarkable smoothness. Drying is done in tunnels, and here the clay shows a tendency to crack badly unless properly handled. It is possible that an admixture of the top clay would prevent this. The bricks are burned either in circular down-draft kilns or in up-draft kilns with permanent side walls. The bricks should be burned harder than they are being fired to insure better results.

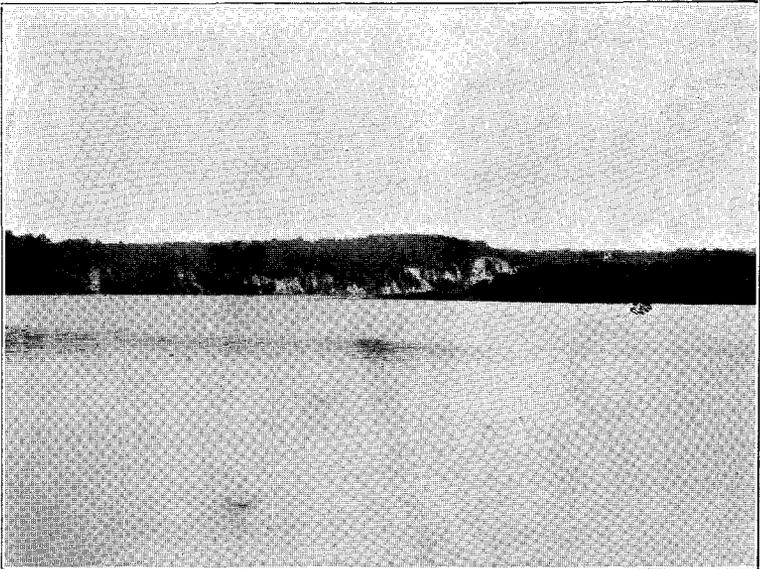
The properties of the blue clay (Lab. No. 1343) are as follows: Slaking, slow; water required, 22; plasticity, excellent; grit, much; air shrinkage, 8.6; average tensile strength, 144.9 pounds per square inch.

## WET-MOLDED BRICKLETS.

<i>Cone</i> .....	<i>010</i>	<i>05</i>	<i>03</i>	<i>1</i>	<i>3</i>	<i>5</i>	<i>8</i>
Fire shrinkage.....	sl. swell.	1.6	1.6	1.6	2.3	2.3	3.3
Color.....	pink	pink buff	pink buff	lt. red	lt. red	lt. red	light brown
Absorption.....	14.6	13.6	12.6	10.7	7.9	7.01	3.6



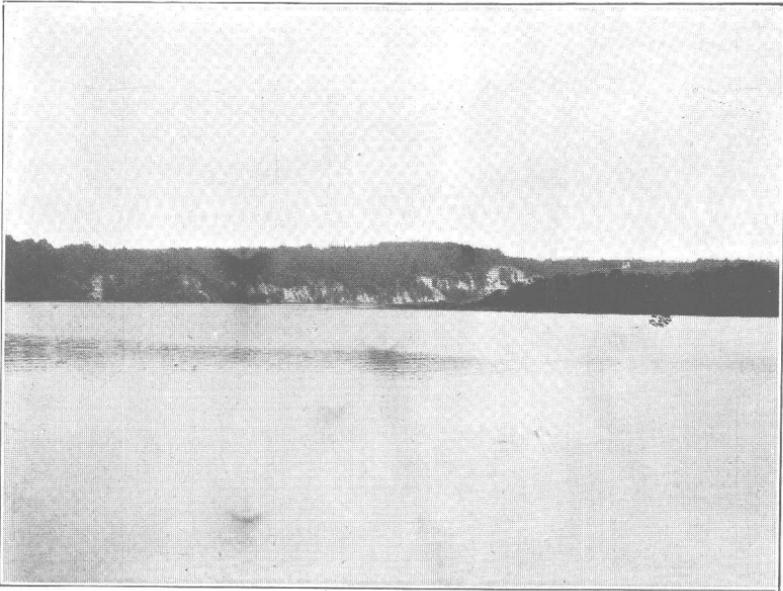
A. Clay bank of Standard Brick Co., near Suffolk.



B. Bluffs of diatomaceous earth (Miocene age) along Rappahannock River, southeast of Wilmont.



A. Clay bank of Standard Brick Co., near Suffolk.



B. Bluffs of diatomaceous earth (Miocene age) along Rappahannock River, southeast of Wilmont.

## DRY-PRESS BRICKLETS.

Cone.....	1
Fire shrinkage.....	2
Color.....	pink

The chemical composition is:

Silica ( $\text{SiO}_2$ ) ..	75.79
Alumina ( $\text{Al}_2\text{O}_3$ ) ..	14.85
Ferric oxide ( $\text{Fe}_2\text{O}_3$ ) ..	3.17
Lime ( $\text{CaO}$ ) ..	.04
Magnesia ( $\text{MgO}$ ) ..	.08
Potash ( $\text{K}_2\text{O}$ ) ..	.75
Soda ( $\text{Na}_2\text{O}$ ) ..	.22
Titanic oxide ( $\text{TiO}_2$ ) ..	trace
Ignition ..	5.06
	<hr/>
Total fluxes ..	99.96
	<hr/>
	4.26

The clay burns steel-hard at cone 03 but does not yield a very deep-colored product. It cannot be stated in advance, without practical trials, whether the clay would yield a good pressed brick.

The yards of the Suffolk Clay Company, and the West End Company are located west of Suffolk and on adjoining properties; in fact the clay deposits worked at the two are probably continuous at the yard of the West End Company. The clay deposit varies from 5 to 15 feet in thickness with very little overburden. It is underlain by a bed of black sand, which in places is quite clayey, but is not mixed with the brick clay. The clay bed has been traced horizontally for at least 200 yards, and contains few stones. No sample of this was tested. The clay is worked up in a stiff-mud machine, and dried in 24 hours in steam heated tunnels.

At the bank of the Suffolk Clay Company, the section shows:

Top soil.....	1 ft.
Yellow clay.....	3 ft.
Blue clay, lower foot sandy.....	9 ft.
Limonite sand.....	1 ft.
Sand.....	8 ft.
Blue marl .....	20 ft.

For brick making the run of the bank, including the sand layer, is used. The blue clay is not safe to use alone by any process of wet-molding, but it gives a harder, denser body. The properties of the brick mixture (Lab. No. 1345) and the blue clay (Lab. No. 1344) are given below:

Laboratory No.	1345	1344
Color moist .....	buff	blue
Water required .....	26.4	31.9
Slaking .....	slow	slow
Plasticity .....	good	excel't
Grit .....	some	little
Air shrinkage .....	10.3	11.6
Average tensile strength .....	142.5	143.8

## WET-MOLDED BRICKLETS.

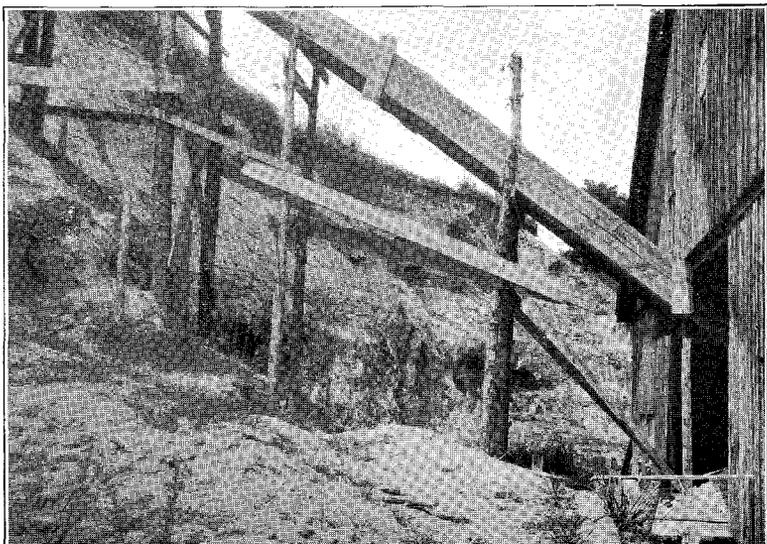
<i>Cone 010</i>		
Fire shrinkage .....	.6	1.3
Color .....	pink	pink
Absorption .....	15.4	16.9
<i>Cone 05</i>		
Fire shrinkage .....	3	4
Color .....	lt. red	pink
Absorption .....	10.6	8.87
<i>Cone 03</i>		
Fire shrinkage .....	3.6	5.6
Color .....	red	lt. red
Absorption .....	7.5	6.11
<i>Cone 1</i>		
Fire shrinkage .....	6.6	7
Color .....	red	lt. br.
Absorption .....	2.6	1.50
<i>Cone 3</i>		
Fire shrinkage .....	7.3	7.6
Color .....	dk. red	drab
Absorption .....	1.04	.20
<i>Cone 5</i>		
Fire shrinkage .....	7	beg. vit.
Color .....	gray	gray
Absorption .....	.60	1.2
<i>Cone 8</i>		
Fire shrinkage .....	5	
Color .....	red gray	
Absorption .....	.02	

## DRY-PRESS BRICKLETS

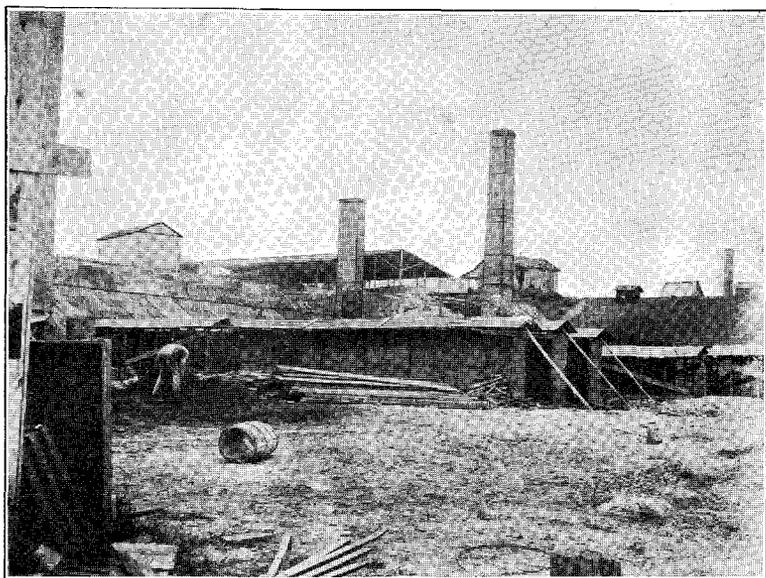
<i>Cone 1</i>		
Fire shrinkage .....	6	7
Color .....	lt. red	lt. br.

Chemical analyses of these two clays gave:

	1345	1344
Silica (SiO <sub>2</sub> ) .....	65.55	64.39
Alumina (Al <sub>2</sub> O <sub>3</sub> ) .....	18.13	20.49
Ferric oxide (Fe <sub>2</sub> O <sub>3</sub> ) .....	5.29	4.40
Lime (CaO) .....	.39	.17
Magnesia (MgO) .....	.51	.91
Potash (K <sub>2</sub> O) .....	1.82	2.31
Soda (Na <sub>2</sub> O) .....	.33	.54
Titanic oxide (TiO <sub>2</sub> ) .....	1.95	.08
Ignition .....	5.98	6.66
	99.95	99.95
Total fluxes .....	8.34	8.33



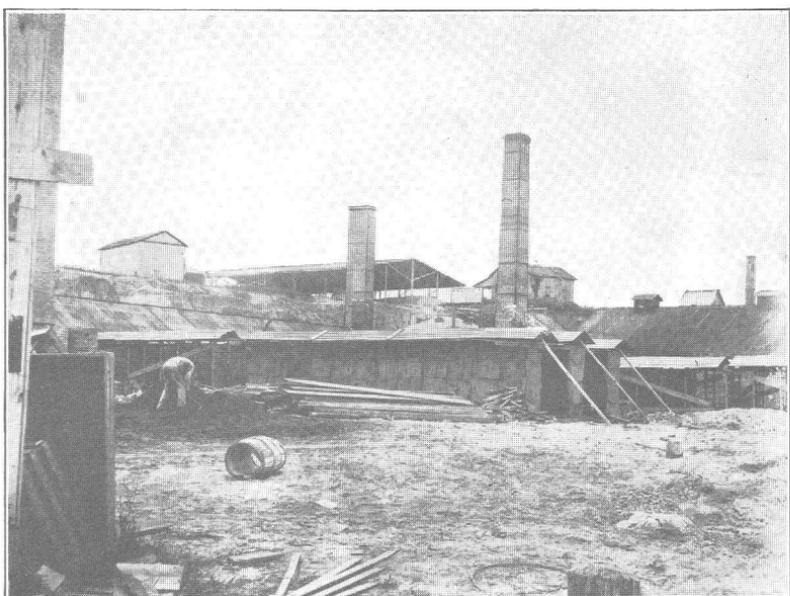
A. Diatomaceous earth overlain by Pleistocene clay at Wilmington.



B. General view of brick plant at Wilmington.



A. Diatomaceous earth overlain by Pleistocene clay at Wilmont.



B. General view of brick plant at Wilmont.

Number 1345 is a very hard-burning clay and becomes steel-hard even at cone 05. It burns to a light red up to cone 03, and deep but good red at cone 1. It is very plastic, and has a high air shrinkage but the fire shrinkage is low. It works well in a stiff-mud machine. It appears to be completely vitrified at about cone 4, and at cone 8 it is nearly viscous. The clay should be fired slowly in the early stages of burning on account of the carbonaceous matter which it contains. It seems probable that this clay could be used for pressed brick. The difference in character between this clay and the blue clay alone is well brought out by the physical tests given above.

Number 1344 also burns steel-hard at cone 05. It is practically vitrified at cone 1, and were it not for its high total shrinkage, it could probably be used for paving brick. It might also serve for common stoneware. This was one of the most dense-burning clays of the entire series tested.

The method of manufacture employed at the Suffolk Clay Company's yard consisted in feeding the clay first into rolls, from which it passed to a double pug-mill. The brick were molded in a Fate auger machine, with end-cut table. Drying was done in tunnels heated by coal, and required 48 hours to prevent cracking. The bricks were burned in up-draft kilns with permanent side walls.

Horrell and Company use a mottled clay, similar to that dug along the Nansemond river near Suffolk. It is dug in the fall and piled up through the winter. The molding is done on a small auger machine, drying on pallets and burning in scove kilns. The clay burns to an excellent color.

#### THE CLAY WORKING INDUSTRY OF THE VIRGINIA COASTAL PLAIN AREA AND ITS FUTURE TENDENCY.

Having given in some detail the properties of the commercially valuable clays which are found in the Coastal Plain region of Virginia, it seems proper to say a few words regarding the present condition of the clay-working industry in this region, and its future development.

As already noted there are five important brick making districts in the Tidewater belt which, in the order of their importance, are: Alexandria, Richmond, Norfolk, Suffolk, and Petersburg. In addition to these there are a number of other places at which one, or at most two, usually small plants are located.

At nearly every one of these localities the product consists exclusively of common red brick. Some yards are equipped with a hand-power repress, and when the occasion demands, repressed brick are supplied, but throughout this entire area, there is only one company which makes a specialty of pressed brick, namely, the Hydraulic Pressed Brick Company at Alexandria. This firm has taken the trouble to separate the different layers of the deposit near its yard, recognizing that they do not all burn to the same color.

In addition to building brick a few drain tiles are made, some hollow brick and boiler brick at one locality, Wilmont.

This represents the range of products now being turned out in the Coastal Plain belt of Virginia, and naturally leads to the conclusion that there is ample room for development, provided the clays are suitable.

From the experiments made in the laboratory the writer feels convinced that the Coastal Plain clays have not yet been put to their fullest use. Some of these clays could be made into a hard brick suitable for use under at least light traffic; not a few could be turned into red earthenware, and many would undoubtedly work up into dry-press brick. The manufacture of hollow brick should also be considered in connection with the expansion of the clay-working industry in this area. There seem strong possibilities too in the buff-burning Eocene clays already referred to as occurring northeast of Fredericksburg.

As regards the methods of manufacture now employed at the active brick yards, it cannot be said that they are in all cases modern. The old method of hand molding, sun drying and scove kilns, is still adhered to, where the clay would stand improved treatment. Curiously enough, where machines are employed for molding, stiff-mud machines are more often seen than soft-mud ones. In such cases the pugging is incomplete, and the drying method not as improved as the molding.

It is true that with the methods now being employed, a good common brick is being turned out; but, with better methods the capacity of the yard could be increased and the cost of production lowered.

Building operations and town or city improvements are going on in many of the towns and cities of eastern Virginia, and there is no good reason why the clays should not be converted into products to be used in these improvements.

## INDEX

	Page
A	
Air Shrinkage.....	73
Alexandria Area and Vicinity, The.....	132-134
County.....	132-134
Alkalies.....	64-66
Aquia Formation, The.....	16-17
Arundel Formation, The.....	15
B	
Ball Clays.....	99
Mills.....	105
Belfield Area, The.....	169-170
Bermuda Hundred Area, The.....	158-159
Black Coring, Effect of Water on.....	71
in Virginia Clays.....	70-71
Blocks, Hollow.....	128
Brick Clay.....	100
Hollow.....	128
Paving.....	126-127
Pressed.....	102-103
Broadway Area, The.....	161-163
Building Brick, The Manufacture of.....	100
Burned Clay, Coloring Action of Iron in.....	58-60
Burning.....	117-126
C	
Calcite.....	51
Calvert Formation, The.....	18
Carbonaceous Matter.....	68-70
Caroline County.....	144-145
Change of Color.....	41-43
Charles City County.....	164-169
Chemical Analysis of Clays, The.....	52-55
Chemical and Physical Properties of the Coastal Plain Clays in Virginia.....	86-91
Chemical Changes.....	41-44
Color.....	41-43
Consolidation.....	44
Leaching.....	43
Softening.....	43-44
Chemical Effect, Mineral Compounds in Clay and Their.....	55-71
Chemical Properties of Clay.....	45-47, 88-91
Chemically Combined Water.....	68
Chester Area, The.....	157-158
Chesterfield County.....	157-159
Choptank Formation, The.....	18-19
Classification of Clays.....	99-100
Based on Fusibility.....	78
Sedimentary Clays.....	34-36

Clay after Mining, Preparation of.....	96-97
Brick.....	100
Chemical Properties of.....	45-47
Coloring Action of Iron in, Burned.....	58-60
Coloring Action of Iron in, Unburned.....	58
Combination of Elements in, The.....	45-47
Defined.....	27-30
Deposits, Secondary Changes in.....	36-45
Effect of Iron Oxide on Absorptive Power and Shrink- age of.....	60
Effect of Lime Carbonate in.....	61-62
Effects due to Variation in the.....	119-120
Minerals in.....	47-52
quartz.....	47
feldspar.....	47-48
mica.....	48
iron ores.....	48
limonite.....	48
hematite.....	49
magnetite.....	49
siderite.....	49
pyrite.....	49
glauconite.....	49-50
kaolinite.....	50
rutile.....	50
calcite.....	51
gypsum.....	51
hornblende and garnet.....	51
dolomite.....	52
Clay, Physical Properties of.....	71
Paper.....	100
Paving Brick.....	100
Pipe.....	100
Products, the Manufacture of.....	98-131
Residual.....	30-32
Uses of.....	32
Retort.....	100
Sagger.....	99
Terra Cotta.....	99
Uses of.....	98-99
Working Industry of the Virginia Coastal Plain and Its Future Tendency.....	175-176
Winning, The.....	92-93
Clays, Ball.....	99
Boulder or Drift.....	36
Chemical Analysis of, The.....	52-55
Classification of.....	99-100
Based on Fusibility.....	78
Drift or Boulder.....	36
Estuarine.....	35
Exploiting and Mining.....	91-97
Fire.....	99
Flood-plain and Terrace.....	35-36
For Common Brick.....	101-102
Highly Refractory.....	78
In Virginia Coastal Plain, Chemical and Physical Prop- erties of the.....	91
Lake and Swamp.....	35
Marine.....	34-35

Clays, Mode of Occurrence.....	27-91
Non-refractory.....	78
Of Low Refractoriness.....	78
Origin, Properties, and Mode of Occurrence of.....	27-91
Properties and Mode of Occurrence of.....	27-91
Prospecting for.....	91
Rational Analysis.....	54-55
Refractory.....	78
Sedimentary.....	32-36
Classification of.....	34-36
Semi-refractory.....	78
Stoneware.....	99
Swamp and Lake.....	35
Terrace and Flood-plain.....	35-36
Ultimate Analysis of, The.....	52-54
Virginia, Black Coring in.....	70-71
City Point Area, The.....	163-164
Coastal Plain Clays in Virginia, Chemical and Physical Properties of the.....	86-91
Coastal Plain, Virginia, Formations of.....	14
Geology of the.....	11-24
Color.....	84-85
Change of.....	41-43
Coloring Action of Iron in Unburned Clay.....	58
Burned Clay.....	58-60
Combination of Elements in Clay, The.....	45-47
Common Brick, Clays for.....	101-102
Consolidation.....	44
Cretaceous Period, The.....	16
Crushers.....	104
Crushing, Dry.....	103
Curle's Neck Area, The.....	154-156

D

Decorative.....	98
Detailed Account of the Virginia Coastal Plain Localities.....	131-176
Details.....	96-97
Determination of Fusibility.....	78
Diatomaceous Earth Deposits, The.....	141-144
Uses of.....	143-144
Dinwiddie County.....	159-161
Disintegrators.....	105
Dolomite.....	52
Domestic.....	98
Down-draft Kilns.....	123-126
Drain Tile.....	127
Drift and Boulder Clays.....	36
Dry Crushing.....	103
Pans.....	105
Dry-Press Process.....	112-114
Drying.....	114-117

E

Effect of Iron Oxide on Absorptive Power and Shrinkage of Clay... ..	60
Lime-bearing Silicates.....	62-63
Carbonate in Clay.....	61-62
Water on Black Coring.....	71

Effects due to Variation in the Clay.....	119-120
General.....	118-119
Of Iron Compounds.....	58
Engineering Works.....	99
Eocene.....	16-17
Essex County.....	140-141
Estuarine Clays.....	35
Exploitation.....	92
Exploiting and Mining Clays.....	91-97
F	
Faulting.....	37-41
Feldspar.....	47-48
Fire Clays.....	99
Proofing.....	128
Shrinkage.....	73-75
Flashing.....	120-122
Flood-plain and Terrace Clays.....	35-36
Fluxing Action of Iron Oxide.....	60
Folding.....	37-41
Formation of Shale.....	44-45
Formation, Aquia, The.....	16-17
Arundel, The.....	15
Calvert, The.....	18
Choptank, The.....	18-19
Lafayette, The.....	20-21
Nanjemoy, The.....	17
Norfolk, The.....	20
Patapsco, The.....	16
Patuxent, The.....	14-15
St. Mary's, The.....	19
Sunderland, The.....	21-22
Talbot, The.....	23
Wicomico, The.....	22-23
Yorktown, The.....	19-20
Formations of Virginia Coastal Plain.....	14
Formations, The.....	14-24
Fort Lee Area, The.....	151-153
Fredericksburg Area, The.....	134-137
Fusibility.....	75-77
Classification of Clays Based on.....	78
Determination of.....	78
Fusion, Temperature of.....	77-78
Future Tendency, Clay Working Industry of the Virginia Coastal Plain and Its.....	175-176
G	
General Effects.....	118-119
Geology of the Virginia Coastal Plain, The.....	11-24
Glauconite.....	49-50
Greensville County.....	169-170
Gypsum.....	51
H	
Hematite.....	49
Henrico County.....	145-151
Highly Refractory Clays.....	78

Hollow Blocks.....	128
Brick.....	128
Ware for Structural Work.....	128-129
Hornblende and Garnet.....	51
Hygienic.....	98

I

Introduction.....	12-14, 98
Iron Compounds, Effects of.....	58
Iron Ores.....	48
Iron Oxide.....	57-58
Fluxing Action of.....	60

J

Jurassic (?) Period, The.....	14-15
Jurassic, Upper (?).....	14

K

Kaolin.....	99
Pit Mining for.....	96
Kaolinite.....	50
King George County.....	137-139
Kilns, Down-draft.....	123-126
Up-draft.....	122-123

L

Lafayette Formation, The.....	20-21
Layton Area, The.....	140-141
Leaching.....	43
Lightness.....	129
Lime.....	60-61
Limonite.....	48
Localities, Detailed Account of the Virginia Coastal Plain.....	131-176
Lower Cretaceous (?).....	16

M

Machines for Preparing Wet Clay.....	106
Magnesia.....	63-64
Magnetite.....	49
Manufacture.....	130-131
Methods of.....	100-103
Pottery.....	129-131
of Building Brick, The.....	100
of Clay Products, The.....	98-131
Methods of Manufacture, The.....	100-103
of Mining.....	93
Marine Clays.....	34-35
Matter, Carbonaceous.....	68-70
Mechanical Changes.....	37-41
Folding, Tilting and Faulting.....	37-41
Mechanically Admixed Water.....	67-68
Mica.....	48
Milford Area, The.....	144-145
Mills, Ball.....	105
Mineral Compounds in Clay and their Chemical Effects.....	55-71
Minerals in Clay.....	47-52

Mining, Methods of.....	93
Preparation of Clay after.....	96-97
Minor Uses.....	98
Miocene.....	18-20
Molding.....	107

## N

Nanjemoy Formation, The.....	17
Nansemond County.....	172-175
Norfolk Area and Vicinity, The.....	170-171
Norfolk County.....	170-171
Norfolk Formation, The.....	20
Non-refractory Clays.....	78

## O

Oldfield Area, The.....	166-169
Outcrops.....	91

## P

Paper Clay.....	100
Patapsco Formation, The.....	16
Patuxent Formation, The.....	14-15
Paving Brick.....	126-127
Paving Brick Clay.....	100
Period, Cretaceous, The.....	16
Jurassic (?), The.....	14-15
Quaternary, The.....	21
Tertiary, The.....	16
Petersburg Area, The.....	159-161
Physical Properties.....	86-88
of Clay.....	71-85
Pipe Clay.....	100
Pit Mining for Kaolin.....	96
Plasticity.....	71
Pleistocene.....	21-23
Pliocene.....	20-21
Pottery Manufacture.....	129-131
Preparation.....	103
of Clay after Mining.....	96-97
Pressed Brick.....	102-103
Prince George County.....	161-164
Process, Dry-Press.....	112-114
Soft-Mud.....	107-108
Stiff-Mud.....	109-111
Properties, Chemical.....	88-91
Physical.....	86-88
Prospecting for Clays.....	91
Pug Mills.....	106
Pyrite.....	49
Pyrometer, Thermo-Electric.....	83-84

## Q

Quartz.....	47
Quaternary, The.....	21

## R

Rational Analysis.....	54-55
Raw Materials.....	101-103, 129-130

Recent.....	24
Refractory Clays.....	78
Wares.....	98-99
Repressing.....	111-112
Residual Clays.....	30-32
Uses of.....	32
Retort Clay.....	100
Richmond Area, The.....	145-156
Ring Pits, Soak Pits and.....	106
Rolls.....	104
Rutile.....	50

S

Sagger Clay.....	99
Screens.....	107
Secondary Changes in Clay Deposits.....	36-45
Sedimentary Clays.....	32-36
Classification of.....	34-36
Segeer Cones.....	79-83
Semi-refractory Clays.....	78
Shale, Formation of.....	44-45
Shrinkage, Air.....	73
Fire.....	73-75
Siderite.....	49
Silica.....	55-57
Silicates, Effect of Lime-bearing.....	62-63
Slaking.....	85
Soak Pits and Ring Pits.....	106
Softening.....	43-44
Soft-Mud Process.....	107-108
Specific Gravity.....	85
Spottsylvania County.....	134-137
Springs.....	91
Stiff-Mud Process.....	109-111
St. Mary's Formation, The.....	19
Stoneware Clays.....	99
Structure.....	98
Structural Work, Hollow Ware for.....	128-129
Sturgeon Point Area, The.....	164-166
Suffolk Area, The.....	172-175
Summary.....	153-154
Sunderland Formation, The.....	21-22
Surface Workings.....	94-96
Swamp and Lake Clays.....	35

T

Talbot Formation, The.....	23
Temperature of Fusion.....	77-78
Tensile Strength.....	71-72
Terra Cotta Clay.....	99
Lumber.....	128
Tertiary Period, The.....	16
Texture.....	84
Thermo-Electric Pyrometer.....	83-84
Tile, Drain.....	127
Tilting.....	37-41
Titanium.....	66

## U

Ultimate Analysis of Clays, The .....	52-54
Unburned Clay, Coloring Action of Iron in .....	58
Up-draft Kilns .....	122-123
Upper Jurassic (?) .....	14
Uses of Clay .....	98-99
Diatomaceous Earth .....	143-144
Residual Clay .....	30-32
Underground Workings.....	93-94

## V

Virginia Clays, Black Coring in.....	70-71
Coastal Plain Localities, Detailed Account of.....	131-176

## W

Washing .....	96
Water .....	67-68
Mechanically Admixed.....	67-68
Chemically Combined.....	68
Weathering .....	103
Wet Clay, Machines for Preparing .....	106
Wet Pans .....	106
Wicomico Formation, The.....	22-23
Wilmington Area, The.....	137-139
Winning the Clay .....	92-93
Workings, Surface .....	94-96
Underground.....	93-94

## Y

Yorktown Formation, The.....	19-20
------------------------------	-------