# STRUCTURAL MATERIALS, ETC.

## NOTES ON THE CLAYS OF DELAWARE.

By George Charlton Matson.

### INTRODUCTION.

During the summer of 1909 the writer devoted about a month to the study of the underground-water resources of Delaware. While engaged in this work he found it possible to make some observations on the mode of occurrence and distribution of clays, and these were supplemented by visits to brick factories wherever practicable. The lack of any detailed reports on the clays and clay-working industries of Delaware has led to the assembling of the information presented in this paper. It is to be hoped that a thorough and systematic investigation of the subject may be made at some future time.

The development of Delaware clays began over 140 years ago with the exploitation of pottery clays near Wilmington. Refractory clay for fire brick and similar purposes was obtained near Newcastle in the early part of the nineteenth century, and brick clays were mined at several places prior to 1850. The production of refractory clays and clays used for pottery has continued to the present time, but the industry is of moderate extent because the deposits are small and the competition with kaolin from other States is keen. As the State has developed the increase in population has naturally caused a greater demand for ordinary building brick and the demand for better brick for fronts of buildings has led to the manufacture of pressed brick. In recent years some draintile has been produced in the State and there should be an increasing demand for it, as larger areas of marsh lands are being cultivated.

The location of the State of Delaware is favorable to the development of cities along the great highways of commerce across its northern portion, and it is that portion of the State which contains the best clay deposits. The city of Wilmington and the other large cities in neighboring States should furnish a market for clay products and thus present a favorable condition for the exploitation of brick clays for structural and ornamental purposes. South of the Chesapeake

& Delaware Canal the demand for clay products is apt to be comparatively small, as the population is largely rural and there are no important cities. However, even in this section of the State some brick can be produced for shipment to large cities, and there should be a local demand for both brick and draintile.

## GEOGRAPHY AND TOPOGRAPHY.

### GENERAL FEATURES.

Delaware occupies portions of two extensive physiographic provinces that may be separated approximately by a line along the Baltimore & Ohio Railroad. The part of the State south of this line lies in the Coastal Plain, which extends from New Jersey southward and westward beyond the Mexican boundary. This province extends beneath the sea to a line where its gently sloping surface gives place to an abrupt descent to the deep-sea floor. The seaward boundary of the Coastal Plain is marked approximately by a line joining points having depths of 100 fathoms; in most places beyond this line the slope of the sea bottom is so steep that it may be compared with that of a mountain range. The landward margin of the Coastal Plain follows the line where the loosely consolidated clays and sands give place to crystalline rocks.

The northern portion of Delaware belongs to the Piedmont Plateau, an extensive physiographic province lying between the nearly horizontal clays, sands, and limestones of the Coastal Plain on the east and the intensely folded rocks of the Appalachian Mountains on the west. This province includes only a small area in Delaware but has an extensive development outside of the State.

The drainage of Delaware is divided between Chesapeake and Delaware bays. The lower portions of the valleys of the streams entering Chesapeake Bay are broad, and the streams are usually affected by tides for some distance from the coast. Farther from the coast the valleys become narrower, their walls are steeper, and the streams themselves have greater fall. However, except in the highlands at the north end of the State the valleys are generally not more than 50 feet below the surrounding country. Near the northern boundary of the State, where the topography is more rugged, some of the larger streams flow in valleys over 350 feet below the tops of the adjacent hills.

### RECENT PLAIN.

The Coastal Plain of Delaware is occupied by unconsolidated or loosely coherent sands and clays showing slight relief. It has been divided into five plains [1] that rise one above another in the form of

[1] Dover folio (No. 137), Geol. Atlas U. S., U. S. Geol. Survey, 1906, p. 1.

terraces. The lowermost of these terraces borders Delaware Bay and forms tidal flats and adjacent lowlands rising only a few feet above tide level. This plain stretches along the entire coast and is the subaerial portion of the plain that extends outward beneath the sea.

### TALBOT PLAIN.

Along the inner margin of the Recent plain, separated from it by a more or less well-developed scarp, is a second terrace known as the Talbot. This plain extends into all the valleys of the streams that enter Delaware Bay and is present also in the western part of the State along some of the streams tributary to Chesapeake Bay. The surface of the Talbot plain is less than 50 feet above sea level in Delaware and it is but little eroded. Over the interstream spaces it is nearly flat, and where it forms reentrants in the stream valleys its slope is scarcely perceptible. It is on the whole a level area such as might be expected where land has been raised above sea level after having been subjected to wave action that had removed the original irregularities of the surface.

### WICOMICO PLAIN.

Bordering the inner margin of the Talbot plain, separated from it by a scarp, is a third plain known as the Wicomico. This plain ranges in altitude from about 40 feet to over 80 feet and occupies a broad area in the Coastal Plain portion of the State. It has a gentle slope from the seaward margin northwestward toward the area of older land. It presents broad tracts of level land in the interstream spaces but narrows greatly in the valleys of the streams. The wider tracts are very nearly level, but the plain has been considerably dissected near some of the streams and locally shows comparatively steep slopes. The greatest amount of dissection is found near the older land in the northern part of the Coastal Plain, where the original surface has locally been destroyed by erosion.

### SUNDERLAND PLAIN.

A fourth plain, known as the Sunderland, lies between the Wicomico terrace and the uplands in the northern part of the State. This plain is higher than the Wicomico and has been longer exposed to erosion, so that it is represented by discontinuous remnants. The range in altitude is difficult to determine, but it is from somewhat less than 100 to more than 150 feet above sea level. The line of demarcation between the Sunderland and Wicomico plains is a scarp that is locally well defined, and a similar scarp marks the inner margin of the Sunderland plain.

### LAFAYETTE PLAIN.

In Maryland there is a plain higher than the Sunderland which has been described by Shattuck.[1] This plain is formed by the surface of the Lafayette formation and its equivalent is probably present in northern Delaware. Above the plains previously described are remnants of an upland rising to somewhat more than 400 feet above sea level. On the interstream spaces this upland has a plain surface that suggests its classification as Lafayette, but this correlation is somewhat uncertain.

## GEOLOGY.

### PRE-CAMBRIAN ROCKS.

The upland in the northern part of Delaware consists of massive crystalline rocks, regarded as pre-Cambrian. These rocks underlie the Delaware portion of the Piedmont Plateau and extend from the northern boundary of the State southward to the vicinity of the Baltimore & Ohio Railroad.

The pre-Cambrian rocks are of various kinds and some of them have undergone considerable metamorphism since they were originally formed, but their varied characteristics and their complex geologic history are not important in a discussion of clays. The only valuable clay deposits of these formations are masses of kaolin that are found in a few localities. This kaolin is the result of the decomposition of dikes of pegmatite that were formed in crevices in still older rocks. In their original state the dikes were composed of quartz and feldspar, with a small percentage of other minerals. When subjected to the agencies of weathering the feldspar of the dikes decomposed into kaolin containing the quartz grains of the original rock. It is these quartz grains that are called sand by the miners.

### CRETACEOUS ROCKS.

The deposits of Cretaceous age, which represent both the Upper Cretaceous and the Lower Cretaceous series, have been divided into several formations. However, for the purposes of this paper it will only be necessary to discuss the major divisions, with incidental reference to some of the clay-bearing formations.

#### LOWER CRETACEOUS SERIES.

The Patuxent formation, belonging at the base of the Lower Cretaceous, has not been recognized at the surface in Delaware, but it is thought to have been penetrated in some deep wells. The Patapsco formation of the Lower Cretaceous is represented by scattered

[1] Shattuck, G. B., Pliocene and Pleistocene: Maryland Geol. Survey, 1906, pp. 80-82.

exposures distributed across the north end of the State. It extends from the Delaware-Pennsylvania boundary in a southerly direction to Wilmington and thence westward to the Maryland-Delaware boundary southwest of Newark. The deposits belonging to this formation occupy a narrow band across this portion of Delaware, but they are obscured by the sands and clays belonging to younger formations, except in the valleys of some of the streams. From the area where the Lower Cretaceous rocks are at or near the surface they extend southward beneath the Coastal Plain, but they have a gentle dip toward the southeast that carries them several hundred feet below the surface beneath the central and southern portions of the State.

The Patapsco formation consists of sand and clay with local beds of gravel. At Wilmington and Newark fine sands are found at the contact with the underlying crystalline rocks, but at other places coarser materials may occur at this horizon. Above the basal beds are lenticular beds of clays and sands that are in most places bright colored but vary from bright red or yellow to gray or drab. The presence of iron concretions and sands or gravels cemented by iron oxide has been noted at many places, and the bright colors are due to iron oxide that may be evenly distributed, giving a uniform color, or may be restricted to patches, causing a mottled appearance. The presence of leaves and other organic matter at some localities gives rise to drab or dark-colored clays, but the areas of such clays are small.

### UPPER CRETACEOUS SERIES.

A narrow band lying south of the outcrop of the Lower Cretaceous rocks is occupied by formations of Upper Cretaceous age. The formations belonging to this series are poorly exposed, although the thickness of the overlying materials near the northern edge of the Coastal Plain is not great. The Upper Cretaceous formations have a general southeasterly dip that carries them far below the surface in the central and southern portions of Delaware; for example, at Lewes they are buried to a depth of more than 1,000 feet.

The lowermost formation (Raritan) of the Upper Cretaceous bears some resemblance to the underlying Patapsco formation, though the color of the materials of which the Raritan is composed is not so striking. This formation is composed of clays of drab, gray, or variegated colors interbedded with sand and here and there with gravel. The colors are due to substances similar to those that color the Patapsco formation, though the oxidation of the iron is usually not as complete as in the older formation. The beds are commonly lenticular and many changes in the character of the materials may be seen in comparatively small exposures.

To the south of the exposures of the Raritan formation is a belt of sands with local clay beds, and above these are greensands with some clay. These are the Upper Cretaceous formations that overlie the Raritan, from which they may usually be distinguished by their relatively smaller percentage of clay and lighter colors, or, in the case of some of the uppermost beds, by the presence of greensand.

## TERTIARY ROCKS.

### EOCENE AND MIOCENE SERIES.

With the exception of the Lafayette the formations belonging to the Tertiary consist, in the lower or Eocene portion, of greensand or of sand with thin beds of clay. Beds of marl are common at certain horizons, especially in the upper or Miocene portion of the Tertiary, and they contain many shells of marine organisms that serve to correlate the formations with exposures outside of the State. The Eocene and Miocene underlie all that portion of the State south of the area of beds of Upper Cretaceous age, but owing to the mantle of Quaternary formations exposures are rare. The clay beds of Tertiary age are thin and scattered. At present none of them are known to have been exploited and owing to the poor exposures it is doubtful if the Tertiary clays will ever be important. In the northern portion of the Coastal Plain of Delaware these formations are not present, but they underlie a large area in the central and southern portions of the State and attain a thickness of several hundred feet near the southern boundary.

### LAFAYETTE FORMATION (PLIOCENE?).

The distribution of the Lafayette formation has been outlined in the discussion of the topography of the Coastal Plain. The deposits included in this formation consist largely of varicolored sand and gravel with thin lenses of sandy clay. The materials are mainly sandy, with colors ranging from gray to yellow or red, the brighter shades predominating. The deposits belonging to this formation are relatively thin, probably averaging not more than 25 feet in thickness, and are therefore of little importance.

## QUATERNARY DEPOSITS.

The Pleistocene and Recent terraces have already been described and their distribution outlined (pp. 186–188). Some uncertainty exists concerning the boundaries of the Wicomico and Sunderland terraces in the northern part of Delaware, and the boundary between the Recent and the Talbot terraces has not yet been accurately determined.

The general character of all the Quaternary deposits is similar, though the materials beneath the Wicomico terrace are somewhat more sandy than those beneath the younger terraces. The Quaternary terraces are underlain by gray or light-yellow sands containing thin lenses of clay. The clay beds are in general only a few feet thick and the deposits are usually sandy, though in a few places they contain lenses of comparatively pure clay.

On the surfaces of the terraces are local deposits of fine-grained loam that as a rule do not exceed 4 or 5 feet in thickness. This loam ranges in color from dark blue near the base of the deposit to light buff at the surface, where the iron compounds have been oxidized. This surface deposit is widely distributed in discontinuous patches, but it is important because it is a source of good clay that can be easily mined.

## GEOLOGIC SECTIONS.

The following sections show the general character of the geologic formations occurring in the Coastal Plain of Delaware. Although these formations vary in composition at different places, the sections here given probably represent the average character of the material they contain. In utilizing sections previously published, the writer has copied the lithologic descriptions but has altered some of the correlations in order to adapt the sections to the major geologic subdivisions which form the units of discussion in this paper.

*Record of United States well at Fort Dupont.* [a]

| | Thickness. | Depth. |
|---|---|---|
| Quaternary: | *Feet.* | *Feet.* |
| Yellowish sand and fine gravel; brackish water | 24 | 24 |
| Cretaceous: | | |
| Rancocas: | | |
| Gray, slightly clayey sand and fine gravel | 16 | 40 |
| Dark-greenish limy sand with shells; contains much glauconite | 20 | 60 |
| Monmouth: | | |
| Dark sandy micaceous clay | 80 | 140 |
| Medium gray sand with very little glauconite | 10 | 150 |
| Brownish-gray sandy clay with some glauconite | 30 | 180 |
| Matawan: | | |
| Dark coarse sand and clay with some glauconite | 17 | 197 |
| Hard light-red, slightly sandy clay | 26 | 223 |
| Dark micaceous sandy clay | 17 | 240 |
| Fine to medium drab or brownish-gray clayey sand with a little glauconite | 40 | 280 |
| Fine to coarse brownish micaceous clay with some glauconite | 20 | 300 |
| Magothy, in part: | | |
| Medium to coarse drab or brownish sand with varying amounts of glauconite and occasionally some clay | 118 | 418 |
| Fine to medium light-gray sand, no clay and very little glauconite | 3 | 421 |
| Raritan: | | |
| Light brick-red clay with some sand | 46 | 467 |
| Fine to medium, slightly clayey pinkish-buff or pinkish-brown sand | 33 | 500 |
| Fine to medium brownish-gray micaceous sand | 10 | 510 |
| Potomac: | | |
| Medium to fine pinkish-brown sand with red and white clay | 130 | 640 |
| Fine to medium light-brown micaceous sand and clay | 10 | 650 |
| Brownish-gray micaceous clayey sand containing lignite | 11 | 661 |
| Fine to medium pinkish-brown sand with beds of pink, red, and white clay and lignite | 49 | 710 |
| Medium varicolored sand with lignite | 15 | 725 |
| Coarse light pinkish-brown sand | 5 | 730 |
| Light-brown sand containing many brown granules; also lignite | 4 | 734 |
| Dark-brownish clay and coarse sand | 2 | 736 |
| Medium pinkish-brown clayey sand | 4 | 740 |
| Brown clay with coarse sand; contains lignite | 5 | 745 |
| Medium brownish clayey sand | 5 | 750 |
| Fine to coarse pinkish-brown sandy clay containing brown granules and lignite | 5 | 755 |
| Medium grayish-brown clayey sand | 7 | 762 |

[a] Fuller, M. L., and Sanford, Samuel, Record of deep-well drilling for 1905: Bull. U. S. Geol. Survey No. 298, 1906, pp. 194-195.

*Record of well at Hares Corner, Newcastle County, Del.*[a]

| | Thickness. | Depth. |
|---|---|---|
| | *Feet.* | *Feet.* |
| Quaternary: | | |
| Yellow clay and sand | 25 | 25 |
| Cretaceous: | | |
| Blue clay | 25 | 50 |
| Red clay | 5 | 55 |
| Yellow sand | 5 | 60 |
| Iron ore (?); very red water | 10 | 70 |
| Yellow sand and water | 10 | 80 |
| White and blue clay | 20 | 100 |
| Red clay; water at base | 75 | 175 |
| Blue clay | 25 | 200 |
| Bluish sand; lignite | 10 | 210 |
| Red and white clay | 10 | 220 |
| White sand; water | 18 | 228 |

[a] Woolman, Lewis, Artesian wells: Ann. Rept. New Jersey Geol. Survey, 1896, p. 140.

*Record of well at Dover, Del.*[a]

| | Thickness. | Depth. |
|---|---|---|
| | *Feet.* | *Feet.* |
| Quaternary: | | |
| Talbot formation: | | |
| Yellow gravel | 7 | 7 |
| Deep orange-colored sand and clay | 4 | 11 |
| Coarse orange-colored sand | 15 | 26 |
| Tertiary (Miocene): | | |
| Calvert formation: | | |
| Light orange-colored sand, finer | 16 | 42 |
| Sandy clay with a few marine diatoms | 12 | 54 |
| Sandy and marly clay | 8 | 62 |
| Sand | 9 | 71 |
| Brownish clay and sand with marine diatoms | 12 | 83 |
| Sand and comminuted shells with marine diatoms and sponge spicules | 7 | 90 |
| Sand | 4 | 94 |
| Sand and broken shell | 6 | 100 |
| Marl | 9 | 109 |
| Micaceous marly sand; some reddish sand grains | 8 | 117 |
| Sand with bad water; comminuted shells, diatoms, and coccoliths | 3 | 120 |
| Sandy clay with diatoms | 8 | 128 |
| Clay with diatoms | 19 | 147 |
| Sand, shells, and diatoms | 3 | 150 |
| Clay with a few diatoms | 5 | 155 |
| Sand with good water | 2 | 157 |
| Clay with pyrite-covered diatoms | 10 | 167 |
| Dark sand, some grains as large as peas; good water | 29 | 196 |

[a] Adapted from Dover folio (No. 137), Geol. Atlas U. S., U. S. Geol. Survey, 1906, p. 5.

*Record of well at Milford, Del.*[a]

| | Thickness. | Depth. |
|---|---|---|
| | *Feet.* | *Feet.* |
| Pleistocene: | | |
| Gravel | 11 | 11 |
| Miocene: | | |
| Blue-gray clay | 14 | 25 |
| Fine gray sand (water encountered at about 30 feet, flows to surface) | 19 | 44 |
| Blue-gray clay | 16 | 60 |
| Fine gray sand | 8 | 68 |
| Blue clay | 2 | 70 |
| Fine gray sand with white particles | 20 | 90 |
| Fine gray sand containing shells | 28 | 118 |
| Blue clay | 3 | 121 |
| Fine gray sand | 16 | 137 |
| Greenish clay | 3 | 140 |
| Fine blue-gray sand (water flows 2 feet above surface) | 20 | 160 |
| Diatomaceous clay | 47 | 207 |
| Gravel, shells, and sand, with water | 21 | 228 |
| Diatomaceous clay | 16 | 244 |

[a] Woolman, Lewis, Artesian wells: Ann. Rept. New Jersey Geol. Survey, 1906, p. 178.

*Record of well at Delmar, Sussex County, Del.*[a]

| | Thickness. | Depth. |
|---|---|---|
| Miocene: | *Feet.* | *Feet.* |
| Fine sand at | ....... | 48 |
| Coarse sand (water at 80 feet) | 37 | 85 |
| Sand | 51 | 136 |
| White sand and soft sand (rock ?) | 21 | 157 |
| Black sandy clay | 11 | 168 |
| Sand, gravel, and pebbles; sand at top and bottom reddish | 39 | 207 |
| Light-colored bluish sand, very hard | 13 | 220 |
| Fine sand | 44 | 264 |
| Light-gray clay (fine white shells at 300 to 304 feet) | 42 | 306 |
| Hard sand | 35 | 341 |
| Marl or clay with fine shells | 33 | 374 |
| Sand | 12 | 386 |
| Clay | 16 | 402 |

a Woolman, Lewis, Artesian wells: Ann. Rept. New Jersey Geol. Survey, 1899, p. 112.

## CLAYS.

### GEOLOGIC AGE.

Practically all the major geologic subdivisions occurring in Delaware contain clays, though not all the clays are of equal economic importance. Moreover, the absence of good exposures prevents the exploitation of many of the older clays, but the Quaternary beds, lying at or near the surface over most of the State, have supplied considerable clay in the form of thin lenticular beds. In addition to the differences caused by the relative accessibility there are marked differences in the values of the different clays; thus a kaolin deposit differs in value from a bed of fire clay, and either of them, where it can be easily mined, will be worth far more than clay that can be used only for common brick. Even brick clays present great variations in value, ranging from those suitable for the manufacture of ordinary rough brick to those fitted for the manufacture of bricks used in the fronts of buildings and for purely ornamental work.

### CLAYS OF THE PIEDMONT PLATEAU.

The rocks of the Piedmont Plateau, when weathered, give rise to clays of various kinds, but the most important, commercially, is the kaolin that has been mined in the northern part of the State. Intruded into the older rocks are a number of masses of pegmatite, and these have weathered to kaolin containing some impurities, chiefly quartz. Kaolin of this type was mined near Hockessin over half a century ago and the industry is still important in that locality. Since it has been found possible to remove the impurities by washing the material has found a ready market. The kaolin deposits at Newark probably belong to the same class as those at Hockessin.

The kaolin deposits of the Piedmont Plateau are residual in origin and locally are covered by a varying thickness of worthless material that must be removed before mining can begin. Owing to the fact that the deposits are obscured by this overlying material it is possible that borings would discover new localities, but no systematic prospecting has yet been done. Where the kaolin underlies the sedimentary formations of the Coastal Plain it is still more effectually concealed, and if deeply buried it is inaccessible.

Kaolin from Delaware has been used chiefly in the production of pottery, but it is also valuable for use in manufacturing paper. The freedom from impurities that would color the burned product makes the Delaware kaolin useful for the manufacture of white burning ware, and it commands a good price for shipment to potteries located outside of the State.

Many of the residual clays of the Piedmont Plateau may be used for the manufacture of ornamental and common building brick. A small brickyard at Newark uses clay that may be either residual or reworked material from the weathered products of the underlying crystalline rocks. Unfortunately the exposures at this place are not extensive and at the time the brickyard was visited but little information could be obtained concerning the origin of the clay. However, it is clear that the crystalline rocks of the Piedmont Plateau were encountered in one end of the pit.

## CRETACEOUS CLAYS.

The Patapsco formation, of Lower Cretaceous age, contains important beds of clay in Delaware, but they have not been extensively utilized. Clay that may belong to this formation has been mined at the brickyard near Christiana, where a brick of good grade for fronts of buildings is produced. A section of the material in the clay pit is as follows:

*Section in clay pit at brickyard near Christiana, Del.*

| | Feet. |
|---|---|
| Buff surface clay | 2–14 |
| Red and mottled clay | 15–20 |
| Dense blue clay | 20+ |

This deposit is of Cretaceous age and belongs either to the Patapsco formation or to the Raritan formation. Similar clays occur along the belt where the Lower Cretaceous and the basal portion of the Upper Cretaceous outcrop across the north end of the State. In addition some kaolin may have been eroded from the Piedmont Plateau and redeposited in the Cretaceous areas, though it is doubtful if such materials have been sought by prospectors. The presence of refractory clays in beds of this age in Cecil County, Md.,[1] suggests the desirability of seeking similar deposits in Delaware.

With the exception of the Raritan the Upper Cretaceous formations are too sandy to be important sources of clay, though local

[1] Ries, Heinrich, Report on the clays of Maryland: Maryland Geol. Survey, vol. 4, pt. 3, 1902, pp. 405–406.

lenses may be present, especially in the Magothy formation, which overlies the Raritan. So far as is known clays of Upper Cretaceous age are not now being utilized in Delaware, and it is doubtful if future exploration of the deposits of this age will result in the discovery of any important clay beds except those in the Raritan formation.

### TERTIARY CLAYS.

The Tertiary formations of Delaware are not important sources of clay, because, with the exception of the Lafayette, the beds are composed largely of sand and greensand marls. For this reason it is as a rule not advisable to seek clay in any of the formations of Eocene or Miocene age, though in places such deposits exist in the form of thin beds. The deposits of the Lafayette formation are largely sand and gravel but contain some thin layers of clay that might be suitable for the manufacture of common brick, though too sandy for the manufacture of brick of the better grades such as are used for ornamental work. At various places on the upland there is a thin layer of yellow or gray loam that may possibly belong in part to the Lafayette. This loam is comparatively free from grit and is suitable for making both common and pressed brick. It is sufficiently plastic to be molded by the stiff-mud process and would doubtless be satisfactory for the manufacture of draintile and similar clay products.

### QUATERNARY CLAYS.

The Quaternary formations are widely distributed in Delaware and have furnished brick clays at many localities. In fact, nearly all the brickyards of the State, with the exception of one at Christiana, use clay from some one of the Quaternary formations. While there is a wide variation in the character of these clays from place to place, they are nearly all suitable for the manufacture of ordinary building brick or draintile, and in a few localities they might be utilized for making pressed brick.

#### CLAYS OF SUNDERLAND FORMATION.

The uppermost Pleistocene formation, known as the Sunderland, extends across the State in the form of a terrace from the vicinity of Newark to Wilmington and thence northeastward to the Pennsylvania-Delaware boundary. The clays of this formation are the probable source of supply for several brick factories in the area adjacent to the Baltimore & Ohio Railroad, but owing to the fact that the formation has not been mapped in detail it is not always possible to tell whether a particular factory is located on beds of the Sunderland formation or of the next younger Wicomico formation. Clay that is tentatively correlated with the Sunderland formation is being used in the factories of the Alvin Allen Brick Co., the Delaware Terra Cotta Co., the Wilmington Brick Co., and James B. Oberly.

These factories are all located in the vicinity of Wilmington and use a loam of buff or yellow color that forms the surface of a terrace of Sunderland or Wicomico age. This loam is widely distributed and it is an important source of clay for common and pressed brick. The clays of the Sunderland formation are usually in the form of thin beds and as a rule it does not pay to work them except where they lie near enough to the surface to be excavated without the necessity of removing a great amount of overburden. It is necessary also to have a large area of the clay beds in order to work the deposits profitably.

### CLAYS OF WICOMICO FORMATION.

The Wicomico formation lies at the surface over a large part of Delaware from the vicinity of the Baltimore & Ohio Railroad southward. In fact, it covers all of that portion of the State except near the coast and in the valleys of some of the streams, where the later Talbot formation is present. Clays form a relatively small percentage of the material in this formation, and where they occur they are in the shape of small lenses that in many places are only a few feet in thickness. Nearly all the clays are sandy, but they are considered satisfactory for the manufacture of common building brick and have been utilized at a large number of factories. The brickyards using these clays are scattered over the State from Delmar on the south nearly to Wilmington on the north. Most of the factories are small, many of them producing rough brick suitable for ordinary structural purposes, and the brickyards are usually located near places where there is a demand for the output. Except near Wilmington very few of the factories using these clays produce any bricks for shipment to distant cities. It is probable that many clays in the Wicomico formation might be utilized in the manufacture of draintile, but as yet there does not appear to be a very large demand for such tile and consequently it has been manufactured at only one or two places. At present the largest plant manufacturing draintile is the one located at Cheswold, near Wilmington.

Clay that has been mined at the following places for the manufacture of brick or tile is tentatively referred to the Wicomico formation, though in a few instances the accuracy of the correlation is uncertain: Blades, Cheswold, Delmar, Ellendale, Harrington, Houston, Laurel, Seaford, Stanton, Townsend, and Whitesville.

### CLAYS OF TALBOT FORMATION.

The Talbot formation contains surface loams and lenses of clay interbedded with more or less sand, and both loams and clays are utilized in the manufacture of ordinary brick. The area covered by this formation comprises a belt along the coast, ranging from 3 to over 6 miles in width, together with some narrow terraces along the streams. The clays are used from both the coastal belt and the fluviatile portions of terraces, the location of the factories being governed largely by the demand. The brick is chiefly intended for local markets and the selection of a site for the brickyard commonly depends on some demand for building brick in the immediate neighborhood. A large number of factories have been opened at several places, but many of them have subsequently been abandoned because of a cessation of the demand for brick.

The clays of the Talbot formation are used chiefly for common brick, but they might also be suitable for other purposes, such as the manufacture of draintile or, where they are especially pure, of other clay products for ornamental work. The following list includes some of the places where these clays have been used in manufacturing brick: Dagsboro, Dover(?), Magnolia (Neale), Milford, Milton, Ocean View, Smyrna, and Stockley(?).

## METHODS OF MANUFACTURE.

There are no factories in Delaware that utilize kaolin and all of this material that is mined is shipped outside of the State. The refractory clays used for fire brick and glass pots are also shipped to other States and only ordinary clays are used in the Delaware factories. The processes of manufacture, comprising the mining and molding of clay and its subsequent burning, differ slightly in different plants, and a brief outline of the methods used is here given.

### MINING.

In most places the clay is mined by hand and shoveled into small cars that convey it to the factory. In a few localities steam shovels are used, but in most of the factories the amount of clay required does not warrant the installation of such machinery. The clay is mined entirely from open pits, and the overburden, if there is any present, is removed either with shovels or, in the larger factories, by means of scrapers operated by horse power.

### MOLDING.

The clay is either molded dry or mixed with a certain amount of water, but the dry-press method is used only in the factory at Christiana. Here the clay is excavated and exposed to the air in open sheds for some time and after being "tempered" in this way it is ground very fine and then molded. The product of this factory is front and ornamental brick of high grade.

The other factories use either what is called the soft-mud or the stiff-mud process. In the soft-mud process the clay is mixed with a comparatively large percentage of water and each brick requires a separate mold. This process is not extensively employed, but it is used in factories near Dover and Wilmington and possibly also in some other localities. In the stiff-mud process the clay is mixed with a smaller percentage of water and is forced from the mold in the form of a long bar that is cut into the desired lengths by means of wires or some other mechanical contrivance. The bar may be shaped so that, in cutting, the severed ends represent the ends of the bricks, which are then commonly designated "end cut;" or it may be shaped so that the severed ends represent the sides of the bricks, which are then called "side cut." Apparently the stiff-mud process is satisfactory, for it is used in nearly all the Delaware factories. In general the bricks appear to be side cut rather than end cut.

For making pressed brick many of the factories in the vicinity of Wilmington permit the bricks that were molded by the stiff-mud process to dry in sheds heated by steam for about 24 hours, when they are taken from the drying sheds and passed through machines where they are re-pressed to give them a smooth surface. This process is employed at several of the larger factories in the vicinity of Wilmington, and the product is a brick of very good grade for use in fronts of buildings. After being molded the bricks are dried, either in open sheds, the moisture being allowed to evaporate gradually, or in sheds heated by steam. Steam drying is employed only in the large factories because the cost of installation of pipes for heating is too great to warrant the use of this method in small plants.

## BURNING.

After being dried the bricks are stacked in kilns and burned. The kilns are either temporary, being constructed each time that bricks are burned, or permanent. The permanent kilns are used only in some of the larger factories, the operators of smaller plants finding it more profitable to construct a kiln for each burning. In the larger factories coal is used for burning, but in the small brickyards wood is the principal fuel. Most of the bricks are bright red or a reddish yellow in color, but in many of the kilns some of the bricks are over-burned and the result is a dark-colored product.

At Christiana, where the manufacture of pressed brick is an important industry, the brick are first burned by the use of ordinary coal and at the conclusion of this operation a quantity of readily combustible coal is thrown upon the fires and the kiln is sealed. This process, known as flashing, covers the surfaces of the bricks with a series of dark spots, giving them a mottled appearance and presumably rendering them more ornamental. The same process is used to a minor extent in some of the large factories located near Wilmington, but the demand for brick of this kind is small.

## LOCAL DETAILS.

The lack of published information concerning Delaware brick factories makes it seem desirable to include here some details about a few of the localities visited by the writer while collecting data for this paper. However, many of the plants were not visited and some new factories have been started since the field work was completed, so that the notes here given do not constitute a complete summary of the brickmaking industry in the State. Moreover, as the conditions governing the installation and maintenance of brick factories change from time to time, many plants come into existence, continue for a brief period, and then cease operations. For this reason the lists already given include some brickyards that have been abandoned and may omit others, especially those that have been recently started. For the same reason some of the plants described below may be no longer in operation.

The American brick-manufacturing plant, 1 mile from Christiana, produces a pressed brick of fine grade for use in the fronts of buildings and other ornamental work. The clay is obtained from one of the Cretaceous formations and is so hard that it must be blasted in order to get it from the pit. After being mined this clay is allowed to dry in open sheds and is then ground and molded by a dry-press method. The bricks are burned in a permanent kiln until they are light yellow in color and then volatile cannel coal is thrown upon the fires and the kilns are sealed. This process of flashing covers the surface of the bricks with a series of dark spots and gives the product a pleasing mottled appearance.

Johnson's brickyard, East Newark, uses a light-yellow clay, having a thickness of over 4 feet, resting on the crystalline rocks of the Piedmont Plateau. The clay is excavated by picks and shovels and is mixed in a pit by the use of a wheel rotated by horsepower. The bricks are molded by the soft-mud process and air dried, after which they are burned in permanent kilns until they have a bright-red or salmon color. The product is a common building brick of good grade.

The Alvin Allen brickyard, Elsmere, obtains clay from the Pleistocene terrace that has been referred to the Sunderland formation, although the accuracy of this correlation is uncertain. This clay has a thickness of 3 or 4 feet where it is being excavated, and it varies in color from a light yellow at the top to blue in the bottom of the pit. It is mined with pick and shovel and hauled in carts to the factory, where it is mixed by means of a modern pug mill and molded by the soft-mud process. After being molded the bricks are placed in sheds having roofs made of loose boards that can be removed to permit the sunshine to reach the bricks. The burned product has a pleasing red color and is used in construction work in Wilmington.

The Wilmington Brick Co.'s yard, Wilmington, uses clay much like that used at the Alvin Allen yard. A section in the pit shows from 4 to 6 feet of fine-grained clay grading in color from light yellow at the top to mottled and blue near the base. The clay is mined by pick and shovel and is first conveyed to a crusher for grinding and then to a pug mill for mixing. The stiff-mud process of molding is used in this factory and the bricks are cut by machinery from the clay bar as it leaves the mold. After being molded the bricks are placed on iron plates, resting on steam pipes, where they are dried before burning. For the manufacture of common brick the product is taken directly to the kilns, but a portion of the bricks are allowed to dry for 24 hours and then passed through a re-pressing machine, thoroughly dried, and burned in the same manner as the others. These re-pressed bricks are used for fronts of buildings and in ornamental work, and the number manufactured depends entirely on the demand. The bricks manufactured at this plant vary in color from light to dark red, depending on the character of the atmosphere in the kiln; the lighter colors being produced where there is an abundance of oxygen to oxidize the iron compounds and the darker colors resulting from a deficiency of oxygen.

At the Delaware Terra Cotta Brick Co.'s yard, Wilmington, the clay used is similar to that used by the Wilmington Brick Co., and the process of manufacture is essentially the same, except that a steam shovel is used in mining and the clay is conveyed from the pit to the mill by a horse car. Both common and re-pressed brick are manufactured and the product of the factory when properly burned has a pleasing red color.

At James B. Oberly's brickyard, Wilmington, the deposit used consists of about 4 feet of fine-grained clay varying in color from light yellow at the top to mottled or blue near the base. It is hauled a short distance from the pits to the plant, dumped upon a platform, and then shoveled into crushers. The clay from the crushers is mixed in a pug mill and is afterward molded by the stiff-mud process. The bricks are then dried in a shed heated by pipes through which the exhaust steam from the machinery is forced. After drying for 24 hours enough of the product is re-pressed to supply the demand for front and ornamental brick. After being thoroughly dried the re-pressed bricks are stacked in the center of the kiln and those that have not been re-pressed are placed around the outside. In burning, anthracite coal is first used and this is followed by ordinary bituminous coal and finally by gas-producing coal. This arrangement of the fuel gives the brick a darker color than it would have if burned in the ordinary manner, because the fire gases from the gas-producing coal reduce some of the ferric oxide to ferrous compounds.

The brick factory at Harrington uses a sandy clay from the Wicomico formation and produces common building brick. The clay is of light-gray color and the deposit is reported to have a thickness of 10 feet, although only about 4 feet of the upper portion is utilized. The clay is mined by pick and shovel and after being mixed in a pug mill is molded by the stiff-mud process. The bricks are burned in a temporary kiln, wood being used for fuel. The product is a porous sandy brick that varies in color from red or yellow in the upper part of the kiln to brown or black near the base, where the fire gases come into contact with the brick and prevent the complete oxidation of the iron compounds in the clay.

Similar brickyards are located near Houston, Bridgeville, and Delmar, and one of much the same sort was formerly operated near Townsend. All these plants used clay from the Wicomico formation.

The Dover Brick Co.'s yard, Dover, uses clay that has been referred to the Talbot formation. The deposit consists of about 12 feet of light-gray clay which is so pure that fine sand must be mixed with it to prevent excessive shrinking while the bricks are drying. It is covered by an overburden consisting of 3 feet of sand and gravel. The bricks are molded by the soft-mud process and burned in up-draft kilns, using either wood or coal for fuel. The product is a light to dark red brick that is extensively used in the construction of buildings in Dover.

# CLAY IN THE PORTLAND REGION, MAINE.

By Frank J. Katz.

## FIELD STUDIES.

This paper is based on geologic studies of the area in Maine covered by the Portland and Casco Bay sheets of the Geological Survey's topographic atlas of the United States. The field work was done in the summer of 1911 and was a detailed areal survey of the major part of the region, in the course of which many sections of the clay formation discussed below were studied and its boundaries mapped.

## THE CLAY.

*Distribution.*—The clay is distributed widely throughout the lowlands about Back Cove and the estuaries of Presumpscot, Fore, New, and Saco rivers. (See fig. 23.) Through the townships of Saco, Old Orchard, Scarboro, South Portland, and parts of Westbrook and Portland, the clay forms a practically continuous flat belt, roughly 6 miles wide, interrupted only by hills that are for the most part isolated and small. In a large part of this region the clay is concealed by overlying sands. To the west and north from this belt clay occupies the valleys and extends up several of them for some distance beyond the region here considered. Along the shore and around the estuaries the elevation of the top of the clay ranges from about tide level to 20 or 30 feet, and farther inland it slopes up to broad flats which are between 70 and 100 feet above the sea in the continuous belt just mentioned. The clay rises gradually in the valleys to the north and west to a maximum height, within the region studied, of about 200 feet on Little River, in the northwest corner of the Portland quadrangle.

*Appearance and character.*—The clay is for the most part olive-gray to blue-gray in color. It is exceedingly fine grained. The margins and base of the clay are in places sandy and such parts are yellowish or a light rusty brown. Although sporadic bowlders are found within the clay, it is remarkably free from sand and pebbles. The material is very uniform in grain and color (except where it is sandy) and no distinct bedding or other structures can be recognized in fresh exposures. However, when the clay in natural and artificial exposures dries, it breaks up into very small blocks bounded by uneven, approximately horizontal surfaces (bedding) and a roughly rectangular system of close and short, nearly vertical cracks. The cracks have very commonly a thin black stain. When thoroughly dry the clay is a light drab-gray in color and the stains bleach to brown.

*Recognition in the field.*—The clay has topographic forms so distinct that it is as a rule easily recognized in the field. The highest surfaces of the clay deposits are generally broad and flat or very gently sloping. All the flat or nearly flat areas in the Portland region are either clay or sand plains. The latter are readily distinguishable by

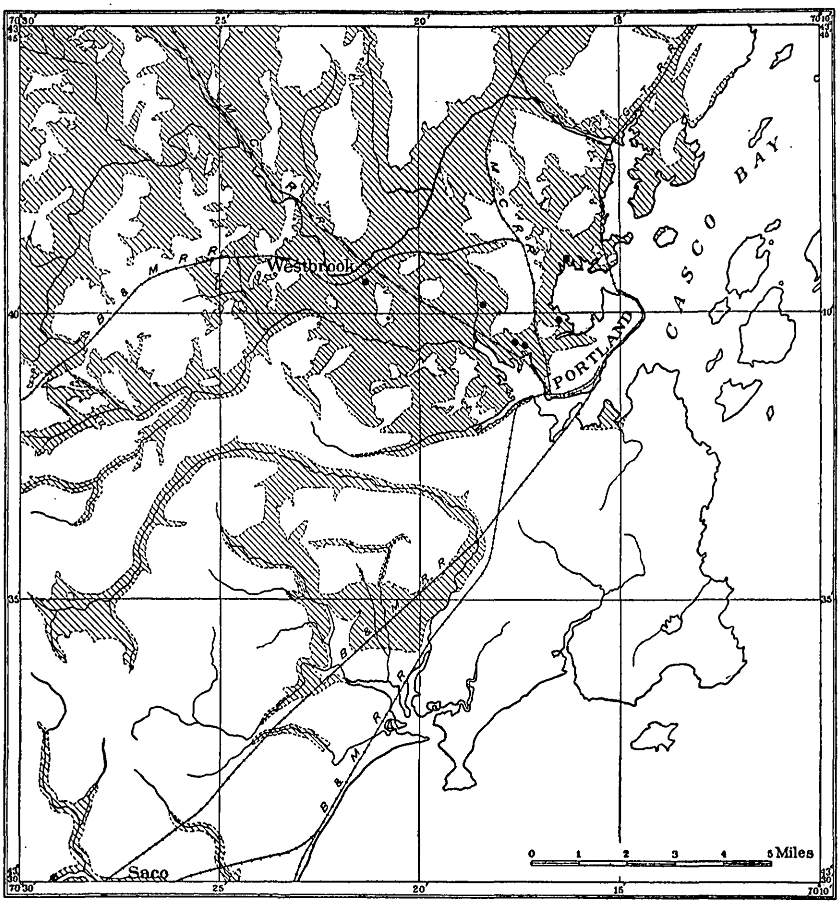



FIGURE 23.—Sketch map of the Portland region, Maine, showing location of principal clay deposits, brick yards, etc. Shaded areas indicate clay; ● clay bank, brickyard, or tile factory.

their sandy soils and especially by the heavy sandy roads which cross them. Some clay flats, particularly those in the lowlands, are unbroken by drainage lines throughout considerable areas, but for the most part the clay deposits are cut by steep-sided gullies, so that gullied surfaces with rounded contours are characteristic. In natural wave-cut exposures along the shore, in railway and road cuts, and in excavations the clay is readily recognized. There are good exposures along the shore in Falmouth Foreside, along the Maine Central Railroad in Portland and Windham, along the Portland-Saco electric line in Scarboro, and on many of the roads, particularly in Gorham. In those areas where the clay is covered by sands the larger streams have cut through the sands into the clay. Along such valleys the top and limit of exposure of the clay is marked by springs and seepages. The clay areas in general are characterized by an absence of bowlders, gravel, etc. The roads that are not surfaced also aid in the recognition of the clay. Where they traverse the clay they are free from pebbles and cobbles. In dry weather they are very hard and covered with fine light-gray dust, and in rainy weather with sticky gray mud. On slopes and where well crowned such roads remain hard even during periods of heavy rains and dry very quickly because of the compact and impervious character of the clay.

*Thickness.*—In the coastal region a thickness of approximately 70 feet of clay is indicated by drill records from Fore River, where the bottom of the clay has been found at some 50 feet below tide.[1] There is an aggregate thickness of about 100 feet on the sides of the valley of Little River. A well in the center of Scarboro Township pierces 43 feet of clay between sand above and gravel below. Inasmuch as the clay lies in depressions in the older formations its thickness may be expected to be irregular but in general to decrease toward the margins of the clay bodies.

## GEOLOGY.

The clay formation in the Portland region is a sheetlike body of fairly uniform character, whose thickness ranges up to about 100 feet. It has in general an approximately plane upper surface with gentle eastward and southeastward (seaward) slope. Locally it contains shells of marine animals. It lies unconformably upon glacial drift and is in part covered by considerable beds of sand which are traceable northwestward to the region where they appear to merge into glacial deposits. The clay is therefore assigned to the Pleistocene, the epoch of glacial occupation of Maine. The marine origin of the clay, which is suggested by its distribution along the coastal region and in the valleys tributary to the coast, is established by the marine shells it contains. The clay deposits are similar to the clam flats of the present day and are evidence that during the time of their deposition the ocean spread over and in places submerged to depths of more than 200 feet parts of the present coastal lands.

## UTILIZATION.

The clay of this region is used chiefly for making common brick. One plant uses local clay for draintile and mixes it with fire clay from other regions for the manufacture of refractory wares.

[1] Clapp, F. G., Underground waters of southern Maine: Water-Supply Paper U. S. Geol. Survey No. 223, 1909, p. 107.

In and near the city of Portland there were in 1911 three brickyards in operation, and near Saco there were two. The one plant in Westbrook was not running. Two of these plants make brick by the old wet-mud process, using horsepower for mixing, etc. The other plants employ modern power-driven machinery.

The plant of William Lucas, on Brighton Avenue in the outskirts of Portland, is on a wide, flat tract of clay, of which about 10 acres has been worked over. The clay here is of an olive-gray color and in its upper portion uniformly clean except for sporadic pebbles and small bowlders. At a few points where the bedrock surface is exposed in the bottom of the pit locally as much as 4 feet but generally only a thin layer of the clay is sandy, very fine textured, and yellowish or brownish in color. The banks are at present about 8 feet high. The clay in them is moderately dry and hard. It is mined by undercutting the face with pick and shovel and prying it down with bars. About 18 inches of overburden (sod and soil) is stripped and hauled off before the clay bank is broken down. The drainage of the pit is natural and easy to a brook near by. The floor is kept above the drainage level. All material broken from the face of the bank is trammed in horse cars to the foot of an incline leading to the mill, and before it ascends sand is thrown into each car in the proportion of approximately 1 part to 9 parts of clay. The cars are dumped on the upper floor of the mill, whence the material, to which water is added in dry weather, descends through a grinder and pug mill to auger brick machines with automatic cutting tables. The capacity of the machines is 45,000 common brick per day. The plant has two sets of machines, electrically driven, but only one is used at a time. The bricks are air-dried in sheds, 14 days being required for drying in fair weather. They are burned with wood fires for 12 days in common scove kilns. The shrinkage is one-eighth inch in length, about half being due to drying and half to burning. About 35 men are employed at the plant, which is operated only during the summer and which produces 4,000,000 common building brick a year. The market is entirely local.

The plant at the head of Douglas Street, Portland, belonging to the estate of Melvin Hamblet, has one set of machines driven by steam. In other mechanical respects and in its operation it is like the plant described above. Its output is 3,500,000 to 4,000,000 bricks yearly. There is another large plant of this type in the town of Saco just south of the region here discussed.

Adjoining the Hamblet plant is one operated by S. P. Densmore, where common building brick are made by the wet-mud process. The clay is worked on the floor of the pit and in simple one-horse machines. The bricks are dried in the open and burned in a scove kiln. The capacity of this plant is 18,000 bricks a day, or 1,000,000 to 1,200,000 a season. West of Saco there is a similar but smaller brick plant.

Winslow & Co. operate a large plant between the shore of Back Cove and Forest Avenue, in Portland, where they manufacture vitrified brick, sewer pipe, fire brick, flue lining, land tile, and various specialties in refractory and glazed wares. The operators estimate that on an average not more than 15 per cent of native clay is used in their products, the remainder being fire clay from New Jersey. The native clay is taken from banks on the north shore of Back Cove and landed at the company's wharf. The product is largely sewer pipe composed of 25 per cent native clay and 75 per cent fire clay. A small quantity of land tile, made entirely of native clay, is manufactured. In mixing, a small amount of water is added to the clays and they are mechanically carried to and put through two pug mills and a compound crusher and separator, from which the tempered clay is carried to hoppers and thence delivered to the molding machines. Drying is done in the lofts of the plant, which is warmed by coils through which the exhaust steam from the engines passes. Drying takes 2 to 3 days for small pieces, 8 days for fire brick, and 10 or 12 days for 36-inch pipe. The burning is done in coal-fired down-draft dome kilns, of which there are twenty-five 30 feet in diameter and one 40 feet in diameter. The capacity of the smaller kilns is from 4½ to 5 carloads and that of the larger 7½ to 8 carloads. Pipe, etc., is fired for 7 days and glazed after the sixth day. Fire brick is fired for 13 days. The kilns are two weeks in cooling.

The product is marketed in New England, freight rates making more distant shipments unprofitable.

## FURTHER DEVELOPMENT.

The abundance and variety of clays and the well-established clay industries of other Atlantic States would probably limit the market for present products of the clay of the Portland region, even if transportation rates were not restrictive. Extended utilization of the clay must therefore be dependent on the local market or on the development of other industries in which this clay might be used. Bastin [1] has called attention to the suitability of similar clay in the Penobscot Bay region for the manufacture of pressed and ornamental brick and of Portland cement. For the former industry the conditions would seem to be favorable at Portland.

[1] Bastin, E. S., Clays of the Penobscot Bay region, Maine: Bull. U. S. Geol. Survey No. 285, 1906, pp. 428–431; also Rockland folio (No. 158), Geol. Atlas U. S., U. S. Geol. Survey, 1908.

# DEVELOPED DEPOSITS OF FULLER'S EARTH IN ARKANSAS.

By Hugh D. Miser.

## INTRODUCTION.

Fuller's earth is a clay which has the property of decolorizing or clarifying oils. Its color is generally light brownish or grayish but varies to white, yellow, greenish gray, pink, or even black. The specific gravity is from 1.75 to 2.50. Like ordinary clays, it may or may not be plastic. It is an aluminum silicate, containing more combined water and less alumina than most other clays and an appreciable amount of hydrous silica. The chemical composition of fuller's earth from different localities varies widely and is of no significance as to its commercial value, which must be determined by practical tests with oils.

Fuller's earth is believed to be a decomposition product of hornblendes and augites, rather than of feldspars, which form ordinary clays. Gabbro, diorite, diabase, and basalt are mentioned by different writers as rocks from which fuller's earth is derived. The developed deposits of fuller's earth in Arkansas are of interest for the reason that the earth is found in place and has been derived from basaltic dikes. Residual deposits derived from diabase and gabbro are also known in Saxony. The deposits in Arkansas and Saxony are the only residual deposits known to the writer, the other known deposits being of sedimentary origin. Certain British deposits are stated[1] to belong to the Lower Greensand formation, and the "Fuller's earth group" is mentioned by Dana[2] and Geikie[3] as a subdivision in the Lower Oolite of the Jurassic period. The sedimentary deposits of fuller's earth in the United States belong to the Cretaceous, Tertiary, and Quaternary periods and occur in Alabama, Arkansas, California, Colorado, Florida, Georgia, Massachusetts, New York, South Carolina, South Dakota, and Texas.

[1] Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 6 (cont.), 1898, pp. 408-411.

[2] Dana, J. D., Manual of geology, 1895, p. 775.

[3] Geikie, Archibald, Textbook of geology, 1903, pp. 1131, 1138, 1140.

## LOCATION AND TOPOGRAPHY.

The developed deposits of fuller's earth in Arkansas occur in an area of about 3 square miles which lies between Hot Springs and Benton. (See Pl. IV.) The St. Louis, Iron Mountain & Southern Railway passes through the area about 7 miles west of Benton.

The area in which these deposits occur is rather hilly. The height of the hills does not exceed 150 feet above the main watercourses, or 500 feet above sea level. The area is drained by small intermittent streams which flow to the southeast and empty into Saline River.

The region is wooded with pine and a little oak, but most of the commercial timber has been removed. Only a small portion of the area is under cultivation, as the larger part is too hilly and the soil is too meager and poor for farming.

## HISTORY.

The first deposit of fuller's earth within Arkansas to receive attention was a bed of Tertiary marl clay [1] near Alexander. This bed was opened in 1890 and samples of the earth were tested the same year. The results, however, did not prove altogether satisfactory. Later a bed of clay near Germania was opened, because it was found to possess some of the properties of fuller's earth. This clay was milled at Perrysmith, now Bauxite, but its use for fuller's earth was not successful.

The deposits near Benton were discovered in 1897 by John Olsen, of Benton. Mr. Olsen at first shipped the crude earth to the Fairbanks Packing Co., of St. Louis, by which it was milled and used. He later erected at Klondyke station a plant for milling his crude earth. At present the other operators owning plants within the area are the Fuller's Earth Union (Ltd.), of London, England; the Fuller's Earth Co., General, of Wilmington, Del.; and Fred Rossner, of Little Rock, Ark.

## GEOLOGY.

### GENERAL FEATURES OF THE OUACHITA MOUNTAINS.

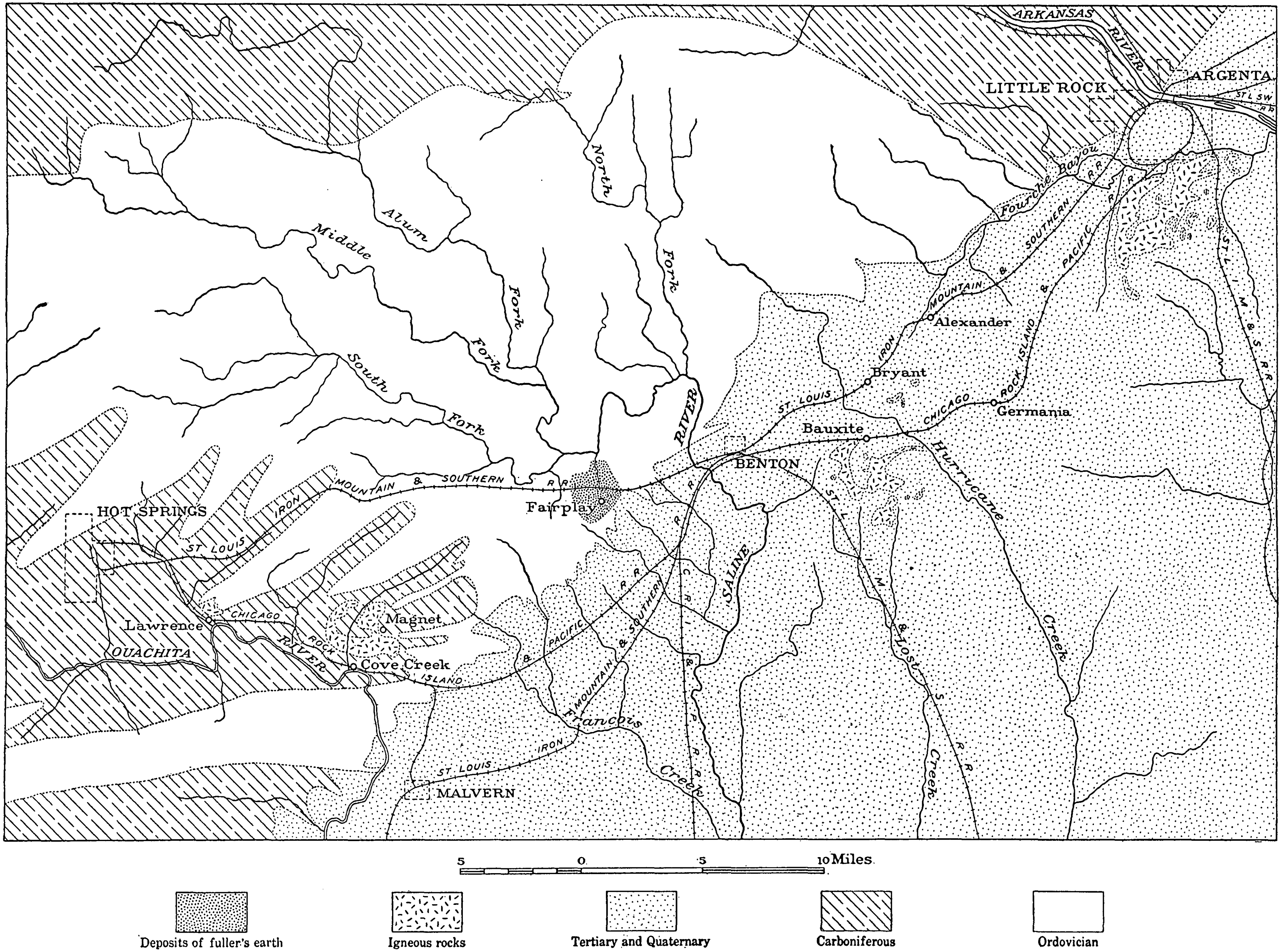
The mountainous area of Arkansas south of Arkansas River is known as the Ouachita Mountains. To the east of these mountains are the Mississippi lowlands, and to the south lies the Red River plain.

The principal structural feature of the Ouachita Mountains is the Ouachita anticline, described by Griswold [2] and Purdue,[3] which extends from the vicinity of Little Rock westward almost to the western border of the State. The truncated east end of this anticline

[1] Trans. Am. Inst. Min. Eng., vol. 27, 1898, pp. 62-63.

[2] Griswold, L. S., Whetstones and novaculites of Arkansas: Ann. Rept. Arkansas Geol. Survey, vol. 3, 1890, pp. 273 et seq.

[3] Purdue, A. H., The slates of Arkansas: Ann. Rept. Arkansas Geol. Survey, 1909, pp. 41-45.




GEOLOGIC MAP OF SOUTHWEST-CENTRAL ARKANSAS, SHOWING LOCATION OF DEVELOPED DEPOSITS OF FULLER'S EARTH.

and the general geology of southwest-central Arkansas are shown on Plate IV. This master anticline consists of numerous simple anticlines and synclines, the whole thus constituting an anticlinorium. The folds are as a rule closely compressed, and the strata stand with a high dip.

The rock formations exposed within the center of this anticline belong to the Ordovician system and consist principally of shales, sandstones, and novaculites. North and south of the exposures of the Ordovician rocks there are enormous thicknesses of shales and sandstones of Carboniferous age. Limestones and unindurated clays, sands, and gravels of Cretaceous age cover a large area within the Red River plain, and like deposits of the Tertiary and Quaternary periods occur in the Mississippi lowlands.

Among these sedimentary formations are several small patches of igneous rocks,[1] the combined exposures of which do not exceed 14 square miles. All the larger masses of igneous rocks which are shown on Plate IV are situated in or near the anticlinal axis of the Ouachita uplift. The igneous rocks of Arkansas belong to the nephelite syenites and their associated dike rocks. They are of the abyssal and intrusive classes. The time of their intrusion is considered to have been about the close of the Cretaceous period. Numerous dikes[2] cut these masses of igneous rocks as well as the Paleozoic strata.

### SEDIMENTARY ROCKS.

The rock formations within the area herein described are the so-called "Ouachita" shale,[3] of Ordovician age, and a bed of gravel belonging to the Tertiary or Quaternary.

The "Ouachita" shale is exposed in relatively wide belts within the Ouachita anticline. It is a black graphitic clay shale which possesses slaty cleavage. The cleavage surfaces are ribboned with black and greenish bands; the former are the wider. These ribbons are well exposed in the fuller's earth mines and in natural exposures. It is from these bands and from siliceous layers in the shale that its dip can be determined. The cleavage as a rule has no relation whatever to the bedding. This shale is jointed and in places intensely crumpled, so that the underground water can circulate freely in it, as is shown by the fairly large amount of water in the mines and wells in this formation.

White quartz veins, having a maximum thickness of 4 feet, are numerous and occupy fissures and bedding planes. The thickness

[1] Williams, J. F., The igneous rocks of Arkansas: Ann. Rept. Arkansas Geol. Survey, vol. 2, 1890.

[2] For description and tabulation of many of these dikes, see Ann. Rept .Arkansas Geol. Survey, vol. 2, 1890, pp. 407-411.

[3] Purdue, A. H., The slates of Arkansas: Ann. Rept. Arkansas Geol. Survey, 1909, pp. 33-34.

of a single vein varies greatly within short distances. No other minerals are associated with the quartz. As seen in the mines the vein quartz is much shattered.

On weathering this shale changes to a plastic clay, which ranges from white to red in color. Residual vein quartz is abundant on the surface in certain localities. The soil, clay, and other débris covering the shale are not more than 2 feet thick, hence natural exposures are numerous along ravines and on hill slopes.

A bed of unconsolidated waterworn quartz and novaculite gravel, composed of pebbles 1 inch and less in diameter, caps many of the highest hills near the border of the Tertiary area. On the crest of the hill north of Fairplay spur there are several large novaculite bowlders embedded in this gravel; the largest is 6 by 12 feet on the exposed face. The nearest outcrop of novaculite is about 6 miles away, and it is not known how these bowlders reached their present position.

## IGNEOUS DIKES.

### GENERAL FEATURES OF OCCURRENCE.

Numerous dikes occur within the area under discussion. Because of their concealment by vegetation and overlying soil exposures are few and they were first discovered in the cuts along the St. Louis, Iron Mountain & Southern Railway. As the residual clay of these dikes was found to be fuller's earth, prospecting for other dikes was carried on and in this way many of them have been discovered.

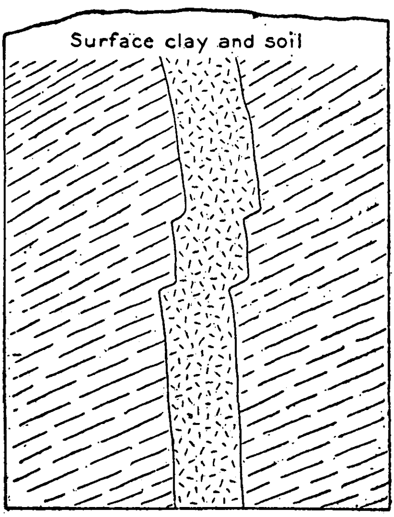



FIGURE 24.—Cross section showing dike altered to fuller's earth. Scale, one-fourth inch equals 1 foot.

The number of prospected and exposed dikes can not be determined because they have been revealed mainly in numerous shafts, mines, railroad cuts, and prospect trenches and can not be traced on the surface from one of these places to another. In the SE. ¼ sec. 23, T. 2 S., R. 16 W., the writer observed at least seven different dikes. In the southwest quarter of this section and the NW. ¼ sec. 26 of the same township and range there are about 24 shafts and openings, all of which are located on dikes. No doubt many of the shafts and openings here are on a single dike, as in the SE. ¼ sec. 23, where two dikes have been mined out from one shaft to another.

The general direction of the dikes is northeast and southwest; it is most likely influenced by the structure of the area, which is complicated by the crumpling and close folding of the shale. The direction of the folds is probably northeast and southwest, as this is the prevailing direction of the axes of the folds a few miles west and southwest of this area. The dip of most of the dikes, according to the writer's observation and statements of the miners, is to the southeast, at angles from 45° to 90°. Some are true dikes, occupying fissures; a few apparently are sills parallel with the bedding. A few occur in fissures beside older quartz veins. The longest dike thus far known is probably half a mile in length. This particular dike has been traced in worked-out mines and prospected for the greater part of this distance. As would be expected, the dikes are not every-

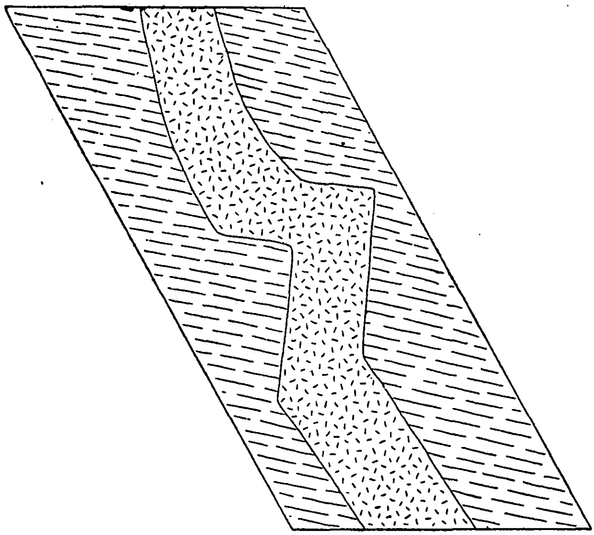


FIGURE 25.—Cross section, in mine, of dike altered to fuller's earth. Scale, one-eighth inch equals 1 foot.

where straight but in many places bend a few degrees to the right or left. A syenite dike, which is the only highly feldspathic dike known within the area, is reported to be 9 feet wide. The other dikes, which are basic, vary from a fraction of an inch to 4½ feet in width. This variation is known to take place in one mine. Within the mines small dikes or "feeders" are frequently observed leading away from the main dike. The walls on either side of some of the dikes are jagged and would in many places fit perfectly if brought together, as is illustrated by figures 24 and 25. One dike is known to occupy a fault plane.

The types of igneous rocks within the area described are ouachitite, syenite dike rock, and biotite monchiquite. E. S. Larsen, of the United States Geological Survey, has made petrologic examinations of the ouachitite and syenite dike rock. The localities of the specimens submitted to him are as follows:

1. Dike in railroad cut 400 feet east of Fuller spur.
2. Shaft 100 yards south of plant of Fuller's Earth Union.
3. Abandoned mine near old spur to west of Armour spur.
4. Shaft about one-fourth mile south of plant of Fuller's Earth Union.
5. Mine at plant of Fuller's Earth Bath Co. (not now in operation).

### OUACHITITE.

The dike in the railroad cut 400 feet east of Fuller spur and the specimen taken from the abandoned mine near the old spur west of Armour spur are stated by Mr. Larsen to be normal ouachitites. His description is as follows:

The ouachitites are dense dark-colored rocks which usually show prominent biotite and abundant augite in the hand specimen; hornblende may be conspicuous in the hornblende variety. The thin sections show that these dark minerals, which form a large part of the rock, are embedded in an isotropic base. Accessory apatite, titanite, and iron ore and secondary calcite, analcite, and zeolites are always present. Small crystals of orthoclase occur in several of the specimens. The index of refraction of the isotropic base was measured by the immersion method in two specimens and found to be $1.490 \pm 0.005$, or sensibly equal to that of analcite. Williams and Kemp [1] describe it as glass, but it is probably analcite. Its character can be proved only by a chemical study of suitable material.

The rock taken from the shaft 100 yards south of the plant of the Fuller's Earth Union is stated by Mr. Larsen to "contain abundant brown hornblende and but little biotite; it is a hornblende ouachitite, but its poverty in biotite places it near the hornblende fourchites." "The specimen from the shaft one-fourth mile south of the same plant," Mr. Larsen states, is "ouachitite, poor in biotite, and with a few altered crystals of olivine; it is therefore near the biotite monchiquites."

### SYENITE DIKE ROCK.

Mr. Larsen describes the specimen from the plant of the Fuller's Earth Bath Co. as follows:

It is a dense gray, finely crystalline rock which shows abundant lath-shaped crystals of feldspar and hornblende in the hand specimen. The rock consists chiefly of orthoclase, albite, brown hornblende, augite, and analcite. Apatite in large crystals, iron ore, and titanite are accessory minerals and secondary calcite is abundant. The orthoclase is in well-bounded lath-shaped crystals, which are locally collected in radial bundles; the plagioclase is less abundant than the orthoclase and is in larger but less regular crystals. The hornblende and augite are subordinate to the feldspars. The analcite is not abundant and occurs chiefly in areas which mold about the feldspars; it is either primary or is derived from a mineral, such as nephelite, which originally occupied this interstitial portion. The rock falls into Williams's division of syenite dike rocks [2] but does not fit accurately into any of his subdivisions.

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[1] Ann. Rept. Arkansas Geol. Survey, vol. 2, 1890.

[2] Williams, J. F., The igneous rocks of Arkansas: Ann. Rept. Arkansas Geol. Survey, vol 2, 1890, pp. 83-99, 367-376.

## BIOTITE MONCHIQUITE.

The rock determined as biotite monchiquite has been taken in considerable quantities from an abandoned mine about 100 yards northwest of John Olsen's plant. It is a dense dark-colored rock. Many of the fragments show large biotite phenocrysts, as much as 1½ inches across the base, in a rather finely crystalline groundmass. The other fragments consist of abundant augite and serpentine embedded in a finer groundmass, as shown in the hand specimen. The writer examined thin sections of the latter variety. The groundmass is composed of much magnetite and small amounts of analcite and apatite, together with some augite and serpentine. Secondary limonite, chlorite, and abundant calcite are present. The augite and serpentine occur in about equal amounts in the section. The serpentine is altered olivine. The biotite is subordinate in amount to both the serpentine and the augite.

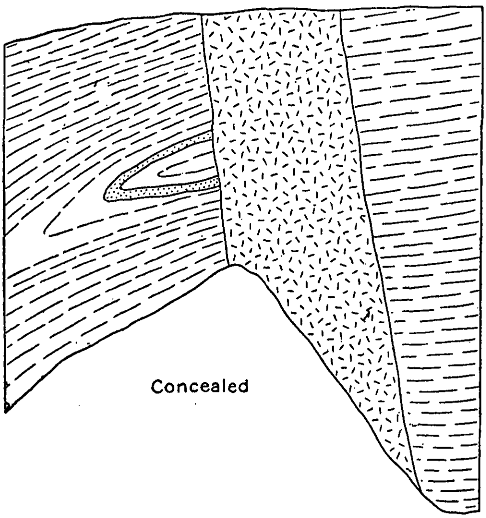


FIGURE 26.—Cross section showing dike occupying fault plane which cuts small fold. Scale, one-fourth inch equals 1 foot.

## DATE OF INTRUSION.

It is known from evidence obtained within this area that the date of intrusion was subsequent to the deformation of the "Ouachita" shale. This shale received the intense folding it now shows at the close of the Carboniferous period; it was probably gently folded at an earlier date. Although the strike of most of the dikes is apparently parallel with the axes of the sharp folds, two were observed to cut the folds of this shale transverse to their axes. Figure 26 illustrates this manner of occurrence. The quartz veins do not cut the dikes but terminate abruptly at the contact of the dike with the shale. This may be taken as proof that the dikes were intruded subsequent to the formation of these veins. Some of the veins also cut the folds in a manner similar to that of the two dikes just described. Many of the veins are therefore post-Carboniferous, and the dikes must have been intruded a considerable time after the close of the Carboniferous period. It was probably the intrusion of the dike material that produced the shattering of the quartz in these veins.

The types of rocks are the same as or similar to those in some of the dikes in other parts of the State. For this reason there seems to be little ground to doubt that all these dikes are genetically connected, and it would follow that their date of intrusion would most likely have been the same. Williams[1] considers the intrusion of the dikes and larger areas of igneous rocks of Arkansas to have taken place about the close of the Cretaceous period.

## ALTERATION OF THE DIKES.

In the lack of chemical analyses of the unaltered rock and its residual clay, the exact nature of the bulk composition change from the original dike to the fuller's earth is not known. The alteration of these dikes into clay was brought about by the chemical action of descending meteoric water that contained salts and acids taken up in passing through the atmosphere and in filtering through the surficial layer of decaying organic matter and the clay and other decomposition products of the rocks at or near the surface.

As has been stated, it is believed that fuller's earth is a decomposition product of hornblendes and augites, rather than of feldspars, as are ordinary clays. This belief is apparently supported by the evidence within this area. The basic dikes, the residual clay of which is successfully used for fuller's earth, contain much augite and a less amount of hornblende, with practically no feldspars. On the other hand, the residual clay from the syenite dike has not proved satisfactory as a fuller's earth; most of its clay is derived from feldspars and only a small part from hornblende.

The alteration of these dikes into clay has extended downward in one place at least to a depth of more than 200 feet, which is the vertical distance from a point on a hill slope to the end of a drift on the lowest level of one mine. The shaft of this mine is in a hollow and is but 160 feet deep. This is the deepest mine within this area and it is said that at this depth only two hard masses of dike rock were encountered. Yet on the same dike and about 500 feet from the shaft of this mine unaltered rock was encountered at a depth of 110 feet from the top of another shaft. In many dikes alteration into clay has extended to depths not exceeding 60 feet.

Here and there bowlders of the dike rock are found in the clay. Many of these and fragments that are blasted from the larger masses in the bottom of the mines have been brought to the surface and are practically the only source from which even fairly fresh specimens of the dike rock can be obtained. Even such specimens are more or less altered, as indicated by the descriptions of the rock sections on page 212. They almost invariably contain secondary calcite, which occupies small cracks and pockets

[1] Williams, J. F., The igneous rocks of Arkansas: Ann. Rept. Arkansas Geol. Survey, vol. 2, 1890, p. 3.

## CHARACTER OF SHALE NEAR DIKES.

The shale into which these dikes have been intruded has weathered into clay only at the surface. Even in contact with the clay of the altered dike it shows little if any decomposition. It still retains its black graphitic nature and is fairly hard. When it is exposed in either the hanging wall or the footwall of a mine for a period of a year or more, it becomes "rotten" in local parlance, the term being used to denote soft or falling slate. Evidences of metamorphism of the shale adjacent to the dikes are not apparent.

The shale, in its natural exposures in the vicinity of the dikes which have altered to clay to the greatest depth, falls to pieces with a dead sound when struck by the hammer, and in weathering into clay it first changes to a light yellowish and greenish shale which is extremely soft. The shale near the dikes which have altered to less depth is much harder and falls to pieces with a somewhat slaty ring when struck by a hammer. It is apparently more siliceous than the shale near the dikes which have decomposed to the greatest depth. This difference in the character of the shale probably has some connection with the conditions favorable to the alteration of the dikes into clay to a greater or less depth. The variation in the shale is shown within short distances and may be due to dissimilar lithologic character of the shale beds. It is best marked in the railroad cuts, where the soft shale occurs nearest the Tertiary border.

## CHARACTER OF CRUDE FULLER'S EARTH.

The fuller's earth of the deposits herein described is the residual clay of igneous dikes, and the clay retains the texture of the unaltered dike. If the original rock contained biotite, as in the biotite monchiquite and ouachitite, this mica, though it is rotten and discolored, is present in the clay. The color of the exposed clay and that near the surface is yellowish to reddish brown and that of the clay which is not near the surface is a light gray to light olive-green. The crude earth has about the same range of hardness as ordinary clay. In proximity to the unaltered rock, where it is less altered, it is harder. All of the Arkansas earth is decidedly plastic, but its plasticity decreases with increasing depth.

The clay is usually jointed. Slickensides are well developed along many of the joints and on the shale in both the hanging wall and footwall. The movement that produced them is believed to have taken place during the decomposition of the dike rock, though nothing was observed that would prove this point.

The minerals commonly found in the clay, besides the aluminum silicates, are calcite, quartz, chalcopyrite, pyrite, and limonite. In a few places the calcite occurs as thin veins which form a network in the clay similar to those in the hard rock. Here and there is quartz which is considered as being an inclusion in the dike rock. It is white and the fragments are usually small. In one mine a beautiful coating of iridescent chalcopyrite upon quartz was seen. Pyrite exists as minute crystals scattered through the clay in the deeper part of one mine. Limonite occurs only within 30 feet of the surface and forms a yellow coating along joints and in cavities and a stain in the clay. Chalybeate water is present in many of the mines and stains the clay where it comes into contact with it. These relations make it apparent that the present deeper water contains carbonic acid but no free oxygen and that the iron has largely been removed from the clay.

## PROSPECTING.

The dikes which have decomposed into clay are exposed only in railroad cuts and here and there in ditches by the roadside; their residual clay is often found in the mats of uprooted trees. If such exposures are not found, it is necessary to dig shallow trenches or prospect pits from 2 to 3 feet deep. The presence of a dike may be detected by the yellowish to reddish-brown color of its clay. The bright-red clay of this area is either Tertiary clay or residual from the "Ouachita" shale. Much of the residual dike clay, when dry, has the appearance of joint clay. In many of the fresher specimens of the clay, even near the surface, the original porphyritic texture of the dike is visible. Where the original rock contained biotite, mica is always present in the surface exposures. The clay that is residual from the shale and occurs on either side of the dike may readily be recognized if it still contains some of its carbonaceous matter or retains its shaly structure. As quartz veins are not everywhere present in the shale, quartz is not always found in the residual clay from it. On the other hand, the residual clay from the dikes is always comparatively free from quartz. In prospecting, it would be well to keep in mind that where the shale has a dead sound when struck with the hammer the dikes have probably altered to a greater depth than where the shale is more sonorous.

## MINING.

At the time of the writer's visit, during the summer of 1909 and fall of 1910, most of the mines were either abandoned or worked out and were filled with water. The following is the general plan of mining followed within the area:

A vertical shaft is sunk in the exposure of the dike or on the footwall side to a depth of about 60 feet. Drifts are then driven along the dike. If the bottom of the shaft at this depth is not within the dike, it is necessary to make a crosscut to reach it. As a rule the crosscuts are driven to the southeast, for the reason that most of the dikes dip in this direction. The drifts are driven with a grade sufficient to permit natural drainage to the sump at the bottom of the shaft. They are usually from 200 to 300 feet long, 3 feet wide, and 6 feet high. The overhand stope, 30 feet high, is mined out by retreating from the far end of the drift toward the shaft or crosscut. As the stope is begun an upraise is driven to the surface at the end of the drift or a shaft is sunk from the surface to the stope in order to provide natural ventilation. When the stope is mined out, the shaft is sunk 30 feet farther, and, if necessary, a crosscut is driven to the dike. Drifts are next run in the dike and the stope is mined out in the same way as on the first level. This process of forming levels 30 feet apart is continued until a grade of earth too hard to work or solid rock is encountered, the mine then being abandoned. A pillar is left near the shaft.

The stope in the best-managed mines is not mined within 30 feet of the surface for the following reasons: Within this depth the clay is highly plastic, stained along joints, and mottled with iron oxide, much more so than at greater depth, and therefore does not make as good an earth as that which is deeper and less plastic and is not iron stained. By thus leaving some of the clay at the outcrop, surface water is prevented from flowing into the mine. Moreover, this clay supports the soft decomposed walls near the surface.

The stope is mined only across the width of the dike, and where the dike becomes too narrow for a man to work, that part of the mine is abandoned. In the best-managed mines props are usually put in rows in the stope and wherever else may be necessary to prevent shale from falling. What little shale does fall is removed from the mines. The shafts are usually well cribbed, sets are put in at regular intervals in the crosscuts and drifts, and lagging is put on the sides wherever necessary and always overhead.

The clay is sufficiently soft to be easily dug with a pick. Digging is especially easy where there are many joints in the clay, but in a few places the calcite veins in the clay make it difficult. When the clay is loosened it rolls or falls down into the drift, where it is shoveled into iron buckets that hold about 300 pounds each. These buckets are taken to and from the shaft upon specially designed trucks which have high handles and run on planks. Hoisting engines are used mostly; horse whims rarely. In many places the drifts turn a few degrees to the right or left in the following dikes. Where the dikes practically pinch out, small "feeders" may continue in the direction of their strike. The miners say that these feeders may be found to widen out again if they are followed.

## MILLING.

The mined clay is stored in sheds at the mines. Thence it is hauled in a farm wagon or two-wheeled cart to the mill, where it is again stored in sheds long enough to become more or less dry. It is next fed into a machine which crushes it to pieces about 1 inch across. Thence it is run into iron cylinders, where it is almost completely dried by hot air or a steam jacket. After drying, the earth is broken finer, then pulverized, and elevated into bolting reels such as are used in flour mills. In one mill reels are not used, but the fine earth is drawn off from the coarser material by an air current produced by a suction fan. At some plants the finished product is not coarser than 80-mesh; at others earth not coarser than 120-mesh is produced. After sizing, the earth is fed into sacks which contain from 225 to 400 pounds each. It is then ready for market.

Most of the earth is free from mica. Clay with a considerable amount of mica is not used, for the reason that the mica clogs the bolting cloth and is a waste product. Moreover, it is not known that the mica benefits the earth by possessing any desirable properties. Every dike of clay can not by itself be manufactured into a good earth. It is sometimes necessary to mix, in definite proportions, clay from two dikes of unlike texture and somewhat different composition in order to prepare an earth of marketable grade. The required proportions for mixing, when mixing is necessary, and the exact method of treatment in the manufacture are known to none except those of long experience in mining and milling the Arkansas earth. Because of the lack of this knowledge, much Arkansas earth that has been put on the market has proved unsatisfactory.

## OUTLOOK FOR THE INDUSTRY.

The area containing the deposits here described is near the center of the Arkansas region of igneous intrusions, on the east border of the area in which rocks of Paleozoic age are exposed. With the exception of those within the large masses of igneous rocks, no dikes are exposed outside of the Paleozoic area. None are known within the area of Tertiary rocks. Hence the prospecting of dikes for fuller's earth must necessarily be carried on within the Paleozoic area.

Igneous dikes are reported as far west as Crystal Springs, Montgomery County. Williams and Kemp[1] describe 280 dikes, and this number probably represents only a small portion of the dikes within the State, for the reason that the exposures of the dikes are not numerous over much of the area of intrusions, and again only small areas were carefully mapped for their report. Of this number but 11

[1] Williams, J. F., and Kemp, J. F., Ann. Rept. Arkansas Geol. Survey, 1890, vol. 2, pp. 407-427.

that are more than 1 foot thick are mentioned as being completely altered into clay, and it is only these 11 of the 280 that may possibly be mined for the production of fuller's earth. At least three of the 11 contain mica, which if present in large amount is objectionable in the milling of fuller's earth. The depth of the residual clay of these 11 dikes is not known, and it is likely that the clay of most of them does not extend downward more than a few feet.

During the progress of the field work in the Hot Springs area for folio publication by the United States Geological Survey, about 100 dikes, not previously reported by the Geological Survey of Arkansas, were discovered by the writer. Of this number nine are 2 feet or more in width and are completely altered into clay at the surface. It is not known to what depth the clay extends.

The dikes mentioned above do not include those of the area discussed in this paper. Hence it is possible that new deposits of fuller's earth will be discovered at places other than those where it is now mined. It is believed that all the difficulties now experienced in obtaining marketable earth will be encountered in developing new deposits.

## USES AND MARKETS.

The Arkansas earth is used for bleaching cottonseed oil, hog leaf lard, beef tallow, and stearine. When the right kind of crude earth and the proper method of manufacture are used, a satisfactory earth is produced. Yet because of lack of experience in this industry some poor grades of earth have been put on the market. The production of this inferior earth has retarded to some extent the introduction of the Arkansas earth to displace the English earth, which is used mainly by American cotton-oil companies and packers.

The Arkansas earth is not used in refining petroleum. It is said that tests with petroleum have been made and that they were not successful.

The principal markets are St. Louis, Kansas City, Chicago, and southern cities.

## PRODUCTION.

Arkansas was the second largest producer of fuller's earth in the United States from 1904 to 1907, Florida being first in amount of production. During 1909, 1910, and 1911 Arkansas was third in output and value, Florida being in first place and Georgia second.

The amount of fuller's earth produced in Arkansas in 1909 was 2,314 short tons, valued at $18,313; in 1910 it was 2,563 short tons, valued at $29,137.

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# GYPSUM ALONG THE WEST FLANK OF THE SAN RAFAEL SWELL, UTAH.

By Charles T. Lupton.

## INTRODUCTION.

The San Rafael Swell, along the west flank of which outcrop the gypsum deposits here described, is an irregular, somewhat elliptical dome extending northeast and southwest in the east-central part of Utah, east of the Wasatch Plateau and west of Green River. (See Pl. V.) In 1911, while making an examination of the coal along the eastern edge of Castle Valley, which occupies a position low on the west slope of the Swell, the writer crossed the western flank of this uplift nearly to the center at several places. The south end of the dome and the north end of the Water Pocket Flexure also were visited in a reconnaissance way and the deposits of gypsum noted. Notes taken on these reconnaissance trips form the basis of this report.

The greater part of the San Rafael Swell has not been sectionized by the General Land Office. It is therefore impracticable to locate many of the deposits definitely. The accompanying map (Pl. V) is a copy of a portion of the General Land Office map of Utah, with the approximate locations of the outcrop and points where the gypsum beds were noted and examined. The numbers on the map along the lines showing the gypsum outcrop represent localities where the gypsum was examined. These exposures are discussed in order from north to south.

So far as the writer is aware, nothing regarding the gypsum of the San Rafael Swell has before been published.

## GEOGRAPHY.

### LOCATION AND EXTENT.

The San Rafael Swell is 60 to 80 miles long and 20 to 30 miles wide. It occupies the greater part of the area represented by the northwest quarter of the Geological Survey's San Rafael topographic sheet and lies between meridians 110° 15′ and 111° 15′ and parallels 38° 15′ and 39° 15′. The gypsum-bearing rocks in the area under discussion outcrop in a belt ranging in width from a few hundred feet in the vicinity of Cedar Mountain or Red Plateau, at the north end of the area, to 3 or 4 miles near the center of the west flank, along the road leading from Emery eastward to the Globe copper mine.

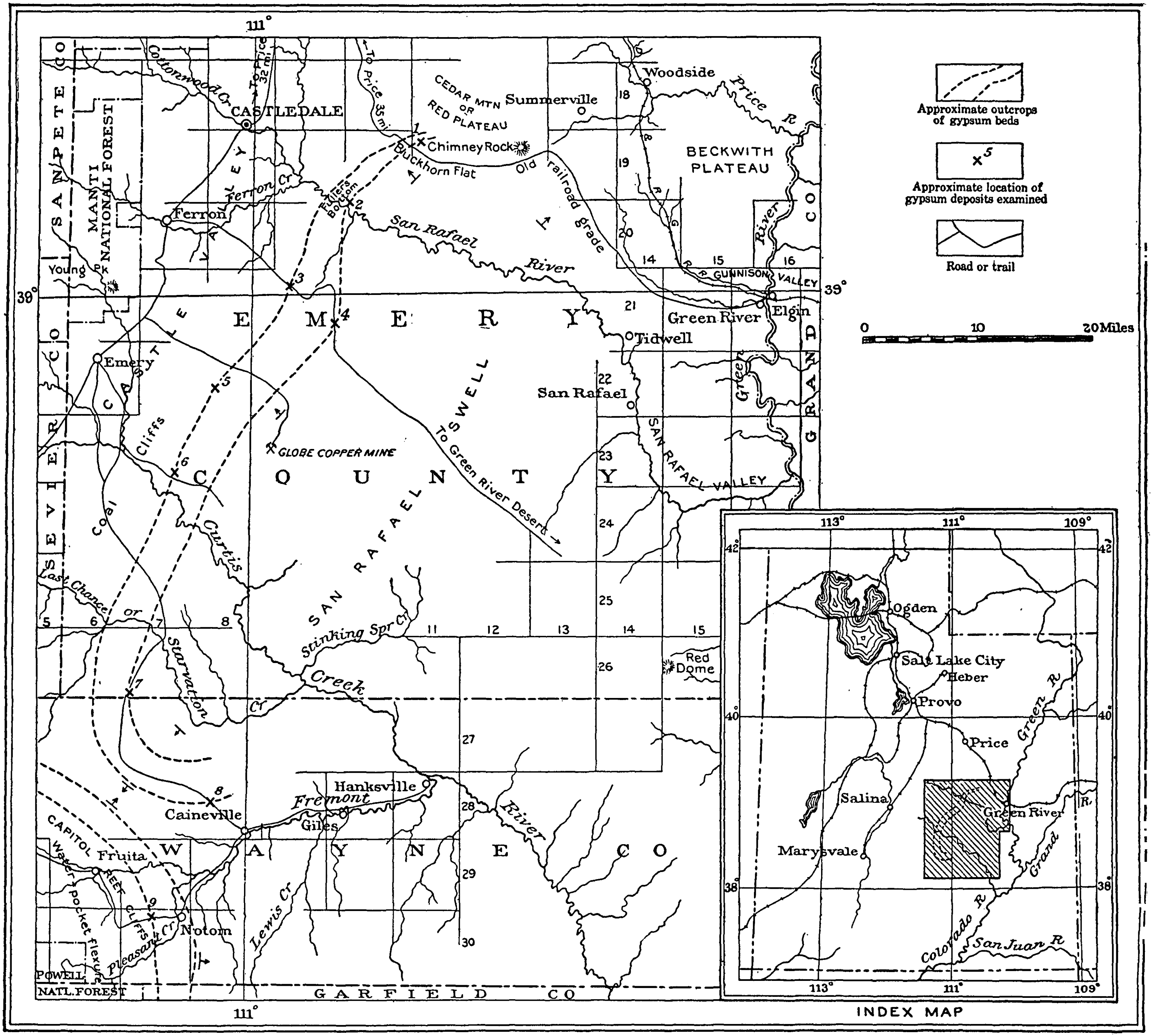
## ACCESSIBILITY.

The gypsum exposures can be most easily visited by leaving the Denver & Rio Grande Railroad at Price, from which a daily stage traverses approximately the entire length of Castle Valley to Emery, 63 miles to the southwest. At any of the towns between Price and Emery (Cleveland, Huntington, Castle Dale, and Ferron) conveyances may be obtained for a trip to the gypsum beds, which outcrop several miles to the east. Probably the most convenient point from which to visit the gypsum-bearing rocks is Cleveland, about 6 miles east of Huntington. A good road leads from Cleveland in a southeast direction to Buckhorn Flat, located directly south of Cedar Mountain or Red Plateau. At the east side of Buckhorn Flat the gypsum beds have been prospected and are reported to be well exposed. From Castle Dale one must follow eastward the course of Cottonwood Creek and San Rafael River. As the trail along the valleys of the streams is very poor, travel by horseback is advised. A fairly good wagon road leads from Ferron, through Molen, by way of Horn Silver Gulch, to the outcrop of the gypsum-bearing rocks about 10 miles to the southeast, in Horn Silver Gulch and Cold Wash. A good road has been built from Emery eastward across the outcrop of the gypsum to some copper prospects known as the Globe copper mine, on the west flank of the Swell. Next to the wagon road leading from Cleveland to Buckhorn Flat, this road would be the best one over which to haul the gypsum should it be mined. From Emery another road 18 miles long has been built southeastward to a possible oil field on the north side of Muddy Creek and crosses the gypsum exposures.

Travel by rail may be terminated also at Salina, on the Rio Grande Western Railway, on the west side of the Wasatch Plateau, where conveyance can be obtained across this plateau to Emery, in Castle Valley. The gypsum exposures situated near the south end of the Swell in the vicinity of Caineville, and also those near the north end of the Water Pocket Flexure, near Notom post office, can be visited most easily by taking the stage from Salina to Loa, in Rabbit Valley, where conveyance can be obtained for the trip down Fremont River to Notom and Caineville.

## CLIMATE.

The climate of the San Rafael Swell is semiarid. A summary of the United States Weather Bureau records shows that the average annual rainfall is scanty, being about 7 inches. The excellent exposures of all the strata noted along the west flank of the San Rafael Swell are undoubtedly due to this semiarid climate.




MAP SHOWING DISTRIBUTION OF GYPSUM DEPOSITS ON THE WEST FLANK OF THE SAN RAFAEL SWELL, UTAH.

## TOPOGRAPHY.

The topography of the area under discussion is especially rugged. Forms cut from massive sandstone, approximately 800 feet thick, underlying the gypsum-bearing formation and outcropping east of it, are the most striking features of the topography in this region. The outcrop of the sandstone has been eroded into peculiar mesas and buttelike forms, which in places suggest castles. To these buttes and mesas Castle Valley undoubtedly owes its name. In many places the walls of these mesas, buttes, and scarps are almost vertical cliffs 300 feet or more high. The outcrop of this sandstone surrounds the central part of the Swell, which is locally known as Sinbad. The topography of the areas of gypsum-bearing rocks is in most places comparatively smooth, except along the streams, where badlands are common. The harder strata on the west flank of the Swell form the tops of "steps," and the softer strata the "risers" between them. The topography is of this character as far as the top of the Wasatch Plateau, the "steps" becoming higher as the plateau is approached. Taken as a whole, the topography of the San Rafael Swell is of badland character.

## GEOLOGY.

The gypsum-bearing rocks are of Upper Jurassic age and are the approximate equivalent of the Flaming Gorge formation of Powell.[1] They rest with apparent conformity on a massive cross-bedded sandstone, which is the Gray Cliff sandstone of Gilbert's Henry Mountains section, regarded as the same as the White Cliff sandstone (Upper Jurassic) of southern Utah and the Uinta Mountains. There are about 1,350 feet of strata, mainly reddish in color, with two gypsum-bearing zones, one 200 feet below the top and the other 200 feet above the base. Between the two gypsum zones there is a series of red and gray sandstone and sandy shale about 950 feet thick. The beds thus described correspond closely with the Flaming Gorge formation described by Gilbert [2] as occurring in the Henry Mountains region, a comparatively short distance south of the San Rafael Swell, where he determined the thickness to be approximately 1,200 feet.

Above these rocks lie 500 feet of conglomerate, sandstone, and sandy shale, greenish drab in color, which apparently corresponds to the larger part of the Henrys Fork formation as identified by Gilbert in the Henry Mountains but which probably should be classified with the Flaming Gorge formation of Powell. Overlying this conglomeratic member, with possible unconformity, is a sandstone that is thought to be the Dakota sandstone.

[1] Powell, J. W., Report on the geology of the eastern portion of the Uinta Mountains and a region of country adjacent thereto: U. S. Geol. and Geog. Survey Terr., 2d div., 1876, pp. 40, 50, 51, 68, 92, 146, 151-153, 157.

[2] Gilbert, G. K., Geology of the Henry Mountains, Utah: U. S. Geol. and Geog. Survey of the Rocky Mountain Region, 1877, p. 6.

The strata along the west flank of the Swell dip from 3° to 8° NW., but the strata along the east flank are in places much more steeply inclined, ranging from almost flat to approximately 70° SE.

## THE GYPSUM.

### GENERAL FEATURES OF OCCURRENCE.

The gypsum of this area, according to the classification of Hess,[1] belongs to his third group, "interbedded deposits," which were precipitated in a shallow sea into which a large amount of sediment was carried, especially at the beginning and end of the gypsum-forming period. The greater part of the deposits take the form of alabaster. The gypsum of the upper zone has a reddish tint and is not quite so pure as the lower deposits, which are white. The gypsum of both zones is so compact and firm that it can be readily carved. The upper and lower portions of both gypsum belts in most places contain considerable sandstone and sandy shale interbedded with the gypsum. These impure portions probably will never be of value for mining, considering the large amount of pure gypsum in the main parts of the beds.

At several places near the outcrop of the gypsum beds the overlying strata are contorted and deformed. This is probably due to the removal of portions of the underlying gypsum in solution by ground water, and the consequent sinking of the covering strata. The lower beds are purer and thicker than the upper. Sections of the exposures examined, given below in the discussion of the gypsum at the different localities, illustrate this point. Very little selenite or crystalline gypsum was noted.

In most places the upper gypsum bed outcrops in the face of cliffs. This position is due to the character of the overlying and underlying rocks, which are in most places fairly resistant sandstone. The lower beds containing gypsum usually outcrop in a monoclinal valley in a broad belt, which corresponds closely to a true dip slope. The rocks that underlie the gypsum are harder than those stratigraphically above it, and, as the gypsum is comparatively soft, it is eroded with the softer sandstone shales. East of Emery, along the Globe Copper mine road, the lower gypsum bed outcrops for more than a mile on one of these dip slopes.

[1] Hess, F. L. A reconnaissance of the gypsum deposits of California: Bull. U. S. Geol. Survey No. 413, 1910, pp. 7-8.

## DETAILED DESCRIPTION OF LOCALITIES.

### SOUTH OF CEDAR MOUNTAIN.

A gypsum prospect directly south of Cedar Mountain or Red Plateau, at locality No. 1 (see Pl. V), near an unused roadbed of the Denver & Rio Grande Railroad, in the NW. ¼ SW. ¼ sec. 6, T. 19 S., R. 11 E., Salt Lake meridian, has a single opening, a pit about 8 feet deep and 8 feet in diameter. Only unconsolidated conglomerate was to be seen in this pit, on account of caving. On the dump was a large amount of grayish-green sandy shale and some pieces of glistening porous gypsum. It is reported by Parlan McFarlane, of Cleveland, Utah, that the gypsum is at least 30 feet thick and that a number of claims have been staked and recorded in this locality. From the stratigraphic position of the prospect pit this is the lower gypsum horizon. It is quite probable that when the mining of gypsum is begun in the San Rafael region the first shipment will be made from this locality, as there is a fairly good road leading through Cleveland to the railroad at Price and also a fair road leading to Green River on the railroad to the southeast. The gypsum can be mined and moved to the railroad from this place at probably a smaller cost than from any other locality hereinafter described.

### SAN RAFAEL VALLEY.

On the north side of San Rafael River, at the east end of Fullers Bottom, at locality No. 2 (see Pl. V), the lower gypsum-bearing zone was examined and the following section was measured:

*Section of gypsum-bearing rocks at the east end of Fullers Bottom along San Rafael River, Utah.*

| | Feet. |
|---|---|
| Sandstone, grayish, thin bedded, locally has a greenish tint. In many places these strata are much contorted and the strata at the outcrop have a wavy appearance | 50+ |
| Gypsum, fairly pure, becoming less pure at top and base | 30–35 |
| Sandstone, reddish, contains thin veins of gypsum | 10 |
| Gypsum, very pure | 7 |
| Sandstone, reddish, contains thin veins of gypsum | 5 |
| Sandstone, thin bedded, greenish gray | 12–15 |
| Total gypsum | 37–42 |

The route from Castle Dale to this locality is down Cottonwood Creek and San Rafael River. The trip is easily made on horseback, but for wagon or buggy the road is very poor. A good road for the removal of the gypsum from this place could probably best be made along the strike of the rocks to the north and northeast, through Buckhorn Flat to the main road leading from Cleveland to Green River, Utah, which follows closely the old grade of the Denver & Rio Grande Railroad.

A sample of gypsum taken near the center of the upper bench at this locality was analyzed by J. G. Fairchild in the United States Geological Survey chemical laboratory, with the following result:

*Partial analysis of gypsum from east end of Fullers Bottom along San Rafael River, Utah (No. 2).*

| | |
|---|---|
| Lime (CaO) | 32.47 |
| Sulphur trioxide ($SO_3$) | 45.63 |
| Water driven off at 300° C. | 20.54 |
| Chlorine (Cl) | .32 |
| Iron oxide ($Fe_2O_3$) | Trace. |

This analysis shows an equivalent of 97.3 per cent of gypsum. Practically no anhydrite is present. The percentages of lime, sulphur trioxide, and water given in the analysis approach very closely those of pure gypsum, which contains 32.6 per cent of lime, 46.5 per cent of sulphur trioxide, and 20.9 per cent of water. A striking characteristic of this gypsum is the unusually large amount of chlorine it contains, which is about 10 times greater than that in the gypsum from Alabaster, Mich. (See table of analyses, p. 230.)

## HORN SILVER GULCH.

In Horn Silver Gulch (No. 3, Pl. V), approximately 10 miles southeast of Ferron along the wagon road leading from Ferron to Green River Desert, the upper gypsum-bearing rocks are well exposed. The thickness of the only bed of gypsum noted in this immediate region was measured across an outcrop on the south side of the gulch. As noted in the general discussion of the gypsum, this bed has a slightly reddish tint and is much thinner than the beds at the lower horizon. The following section shows the character of the overlying and underlying rocks as well as the thickness of the gypsum at this place.

*Section of gypsum-bearing rocks in Horn Silver Gulch about 10 miles southeast of Ferron, Utah.*

| | Feet. |
|---|---|
| Sand and clay, gray, fine grained; sandstone, conglomeratic at top | 14 |
| Sandstone, yellowish gray to brown; upper 1½ feet very hard and forms a ledge | 4 |
| Gypsum, very slightly reddish, comparatively pure; contains nodules of variegated chert | 11 |
| Sandstone and sandy shale, in places ripple marked, thin bedded; some very resistant beds 2 to 3 feet thick; mainly reddish in color with a few thin bands and streaks of greenish-gray fine-grained sandstone (base unexposed) | 210 |
| Total gypsum | 11 |

A sample of the gypsum near the center of the bed was analyzed by J. G. Fairchild in the United States Geological Survey chemical laboratory as follows:

*Analysis of gypsum from Horn Silver Gulch 10 miles southeast of Ferron, Utah (No. 3).*

| | |
|---|---|
| Lime (CaO) | 32.49 |
| Sulphur trioxide ($SO_3$) | 45.88 |
| Water driven off at 300° C | 20.58 |
| Chlorine (Cl) | .39 |
| Iron oxide ($Fe_2O_3$) | Trace. |

This analysis shows an equivalent of 97.9 per cent of gypsum. Practically no anhydrite is present. The chlorine content is slightly more than that of the sample collected at locality No. 2 along San Rafael River.

The outcrop of this bed of gypsum is near the road connecting Ferron with Green River Desert. To take out the gypsum, however, it would be necessary to make a much better road than exists at present. A fair road leading in a direction north slightly east from a point near this locality and extending practically the entire length of Castle Valley could be used in moving the mined product to the railroad.

## COLD WASH.

In Cold Wash (No. 4, Pl. V), 20 miles east of Emery, gypsum which belongs to the lower horizon outcrops along the road from Ferron to the Green River Desert. A detailed section measured a short distance northwest of Dripping Spring, on the west side of Cold Wash, is as follows:

*Section of gypsum-bearing rocks on Cold Wash about 20 miles east of Emery, Utah.*

| | Feet. |
|---|---|
| Sandstone, thin bedded, grayish in places, tints of red and green | 50+ |
| Gypsum | 35+ |
| Sandstone, greenish gray, thin bedded | 60± |
| Shale and sandstone, reddish, thin bedded | 18 |
| Sandstone, yellowish brown, thin bedded | 15 |
| Sandstone, yellowish brown, massive | 10 |
| Sandstone, maroon and yellowish buff, thin bedded | 15 |
| Total gypsum | 35+ |

In many places it is impossible to obtain an accurate measurement of the gypsum on account of its soluble character, the ground waters having dissolved part of the bed. At the locality above mentioned conditions were such that it was impossible to determine whether the total thickness of the gypsum was seen.

Dripping Spring issues from thin-bedded sandstone about 40 feet below the base of the gypsum bed and naturally it carries a great amount of gypsum. The water, which is cold, has a bitter taste that is emphasized when the water is heated. The bitterness possibly is due to the presence of epsomite, the sulphate of magnesium.

### COLT GULCH.

About 8 miles east of Emery, in an intermittent stream course known locally as Colt Gulch (No. 5, Pl. V), the following section of the upper gypsum rocks was measured:

*Section of gypsum-bearing rocks in Colt Gulch, about 8 miles east of Emery, Utah.*

| | Ft. | In. |
|---|---|---|
| Conglomerate, gray, fine grained; pebbles consist of chert and limestone, ranging from sand grains up to pebbles 3 inches in diameter; contains a few lenses of soft friable sandstone | 8± | |
| Sandstone, gray | 4 | |
| Gypsum, sandstone, and limestone, with some red, gray, and white sandy shale | 16 | 6 |
| Gypsum, pinkish, impure, and very shaly at base, fairly pure at top; contains chert fragments. (This portion of the bed probably corresponds with the section measured at locality No. 3 in Horn Silver Gulch) | 22 | |
| Shale, salmon red, in places greenish gray | 10 | 4 |
| Gypsum, almost pure white | 10 | |
| Shale, reddish, sandy | 1 | 3 |
| Gypsum, somewhat impure | 4 | |
| Clay shale, sandy, salmon-red | 11 | |
| Total gypsum | 36 | |

The above section was measured on the south side of Colt Gulch. There is no good road or trail leading into this gulch, and to take out the gypsum considerable expense for a road would be necessary. This section shows that there is much more gypsum here than in the section measured 8 or 10 miles to the northeast, in Horn Silver Gulch.

### MUDDY CREEK.

On the west side of Salt Wash, north of Muddy Creek (No. 6, Pl. V), 15 miles southeast of Emery and 6 to 8 miles south-southwest of Colt Gulch, a detailed section of the upper gypsum rocks was measured as follows:

*Section of gypsum-bearing rocks on the west side of Salt Wash, north of Muddy Creek, about 15 miles southeast of Emery, Utah.*

| | Feet. |
|---|---|
| Conglomerate | 5 |
| Gypsum; in places has a slightly reddish tint | 52 |
| Shale, interbedded with gray sandstone | 29 |
| Total gypsum | 52 |

It is quite probable that the gypsum shown in the above section may contain sandstone and shale partings, and portions of the bed may be somewhat impure, as the exposure was not good. The gypsum from this locality can be shipped with little difficulty, as an excellent road has been graded from Emery to a point a short distance east of the outcrop. At this locality the road, which follows an approximate dip slope of the strata, is on the gypsum for at least half a mile. Considerable deposits of quartz and gypsum sands cover the surface near the outcrop.

### LAST CHANCE CREEK.

Very little is known regarding the details of the gypsum beds for a distance of 15 to 18 miles to the south from the locality last described. Sections of the gypsum were not measured, but the presence of the upper zone is assured by the "float" and the character of the water in Last Chance Creek where it is crossed by the wagon trail connecting Caineville and Emery, which is stratigraphically above the lower gypsum horizon. The water of this creek is so thoroughly saturated with gypsum and possibly some epsomite that it is practically unfit for the use of man or beast. A few miles south of Last Chance Creek, also known as Starvation Creek (No. 7, Pl. V) a piece of gypsum "float" from the lower horizon was found near the Caineville-Emery wagon trail. The main bed was not seen, but the undulating, contorted character of the strata at this place suggested that as much gypsum lies a short distance beneath the surface as that measured at the exposure on San Rafael River (No. 2). A number of igneous sills and dikes were noted here and some of the pieces of gypsum suggest that it had been slightly metamorphosed by the heat from these intrusions.

### CAINEVILLE.

About 3 miles northwest of Caineville post office, approximately in the center of T. 28 S., R. 8 E., Salt Lake meridian (No. 8, Pl. V), the upper gypsum bed was observed outcropping for 2 miles along the canyon through which the Caineville-Emery wagon trail extends. The bed was not measured in detail, but is approximately 8 feet thick and seemed to be very pure.

### NOTOM.

Along the east flank of the Water Pocket Flexure, near the north side of T. 30 S., R. 7 E., Salt Lake meridian, about 2 miles west of Notom post office (No. 9, Pl. V), a bed of gypsum undoubtedly representing the lower horizon is exposed near the wagon road extending from Fruita to Notom. This outcrop, the exact thickness of which was not measured, is about 75 feet stratigraphically above the massive cross-bedded sandstone to which Gilbert applied the name Gray Cliff. Although the horizon of the upper gypsum bed was crossed in the vicinity of Notom it was not seen at any place. It is probably present, however, as it outcrops a few miles to the north in the vicinity of Caineville.

## OTHER EXPOSURES.

Along the road leading from Emery eastward to the Globe Copper mine both gypsum horizons were noted. The upper or pinkish bed has apparently the same thickness as that noted in Horn Silver Gulch (No. 3). It was impossible to obtain a measurement of the lower bed, as it outcrops on an approximate dip slope for a distance of more than a mile. Gypsum deposits were not observed elsewhere along the west flank of the Swell, but the writer believes that the beds of both horizons are continuous from the north to the south end of the Swell and that they may some day be valuable should transportation become less expensive.

## CHARACTER OF THE GYPSUM.

The gypsum of both horizons is comparatively pure. The lower bed, however, probably contains less impurity than the upper. The upper bed, in addition to the slight discoloration, contains numerous small chert nodules of various colors. These undoubtedly would cause some difficulty in the preparation of the gypsum for plaster of Paris. The lower deposits contain very little chert and are almost white. From these deposits gypsum which would make white plaster could probably be obtained. Certain portions of the upper pinkish bed, which is compact and fine grained, might be used as alabaster, giving a varied effect from the pure white. The lower bed could also be used in this way, as it is apparently as solid as the upper bed. The two analyses taken in this area, together with the analysis of gypsum from other localities in the United States, are given below in tabular form in order to compare the gypsum of this with other fields.

*Partial analyses of gypsum from the San Rafael Swell, Utah, compared with those from other parts of the United States.*

| Locality. | Percentage of gypsum. | CaO. | $SO_3$. | $H_2O$ driven off at 300°C. | Cl. | $Fe_2O_3$. | Analyst. |
|---|---|---|---|---|---|---|---|
| Near Palmdale, Cal. [a] | 72.1 | 27.5 | 33.5 | 15.6 | Trace. | 1.3 | George Steiger. |
| Kern County, Cal. [b] | 79.5 | 28.76 | 37.06 | 17.3 | Trace. | .71 | Do. |
| Alabaster, Mich. [c] | 99.3 | 32.33 | 46.18 | 20.96 | .03 | .08 | Do. |
| Black Hills, S. Dak. [c] | 97.7 | 32.44 | 45.45 | 20.80 | | | Do. |
| Nephi, Utah [c] | ([d]) | 35.29 | 48.14 | 15.88 | Trace. | | E. T. Allen. |
| Fullers Bottom, Utah (No. 2, present report) | 97.3 | 32.47 | 45.63 | 20.54 | .32 | Trace. | J. G. Fairchild. |
| Horn Silver Gulch, Utah (No. 3, present report) | 97.9 | 32.49 | 45.88 | 20.58 | .39 | Trace. | Do. |

[a] Hess, F. L., A reconnaissance of the gypsum deposits of California: Bull. U. S. Geol. Survey No. 413, 1910, p. 30.
[b] Hess, F. L., Gypsum deposits near Cane Springs, Kern County, Cal.: Bull. U. S. Geol. Survey No. 430, 1909, p. 418.
[c] Clarke, F. W., The data of geochemistry, 2d ed.: Bull. U. S. Geol. Survey No. 491, 1911, p. 220 (analyses B, C, and D.
[d] Probably contains anhydrite.

## DEVELOPMENT.

So far as is known to the writer no gypsum is now being mined in the San Rafael Swell region. Except at the prospects south of Cedar Mountain or Red Plateau, described above under locality No. 1, the gypsum of this district has not been prospected. On account of the excellent natural exposures, however, prospecting is unnecessary, as in most places the entire thickness of the beds is well exposed. It is possible that small quantities of gypsum have been used by ranchers and others desiring plaster of Paris or land plaster, but the quantity removed from the field is insignificant. From the description given it is evident that the San Rafael Swell contains an enormous supply of gypsum, but probably no great quantity will be mined until better transportation facilities are available. It would be a comparatively easy matter to extend a railroad spur from either Green River or Price to these gypsum-bearing rocks. A railroad grade has been made through the northern part of the San Rafael region connecting Green River with Price, and although the road has never been used it could be repaired with little labor and expense. As this grade crosses the gypsum beds in T. 19 S., R. 10 E., and as the gypsum-bearing rocks occupy a monoclinal valley, a railroad spur could be very easily projected through the center of the gypsum belt for its entire length. The raw product then could be mined and transported cheaply. Such a railroad would probably induce coal mining in the Cretaceous beds east and south of Emery along Muddy Creek and its tributaries.

Gypsum of the massive variety has a specific gravity of approximately 2.32. This is equivalent to about 145 pounds to the cubic foot. The following estimates are based on the considerations that the gypsum could be mined under cover to a distance of 2 miles from the outcrop, which, with the dip of 3° to 5°, would carry the bed about 800 feet below the surface, and that the gypsum-bearing beds are 60 miles in length on the west flank of the Swell. To be conservative the upper bed is assumed to average 10 feet in thickness, and the lower beds to contain an average of 30 feet of gypsum. These assumed thicknesses probably represent 25 to 50 per cent less than the true average. On this basis the beds of gypsum on the west flank of the San Rafael Swell are estimated to contain 9,701,600,000 tons—2,425,400,000 tons in the upper bed and 7,276,200,000 tons in the lower bed.

# GEOLOGY OF THE SALT AND GYPSUM DEPOSITS OF SOUTHWESTERN VIRGINIA.

By George W. Stose.

## LOCATION.

Large deposits of salt and gypsum are known to occur along a belt of country 20 miles long running northeastward from the village of Plasterco, Va., and lying in Washington and Smyth counties. Much of this territory is in or near the valley of the North Fork of Holston River, and this portion is made accessible to railroad transportation by the Saltville branch of the Norfolk & Western Railway, which joins the main line at Glade Spring. The location and relations of this area are shown in figure 27. Two gypsum plants and one salt or alkali works are now in operation in this area. Numerous old gypsum workings and prospects indicate the extent of the deposits, some of which are at present not commercially workable because of lack of transportation facilities. The active mines, old workings, and prospects are shown on the geologic map in figure 28.

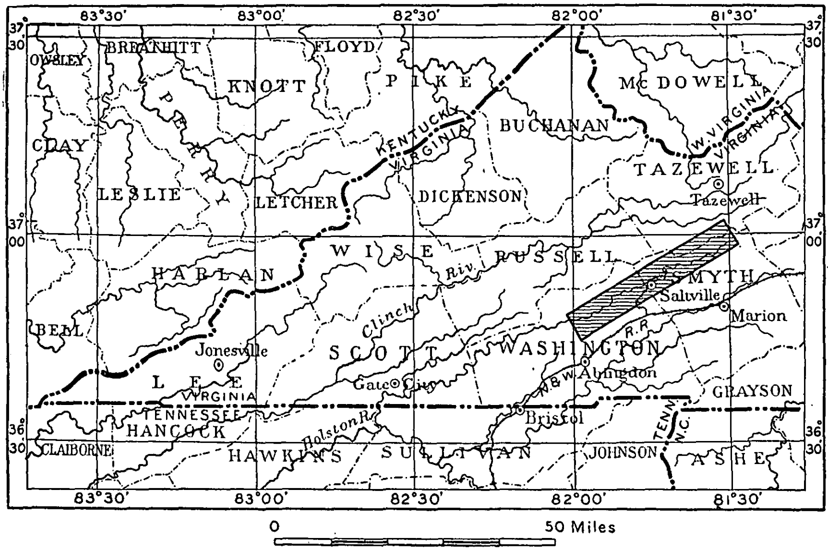



Figure 27.—Index map of southwestern Virginia. The area described and mapped in this report is indicated by the shaded rectangle. Railroad connections for this area only are shown.

## TOPOGRAPHY.

The area represented on the accompanying map (fig. 28) comprises a mountain ridge 1,000 feet high separating parallel valleys and rising above an adjacent deeply dissected plateau. The ridge, named Pine Mountain at the southwest and Brushy Mountain at the northeast, trends in a general N. 70° E. direction and its elevation ranges from 2,500 to 3,000 feet. It is cut nearly at right angles by several deep water gaps through which pass the waters from Clinch Mountain that drain into the North Fork of Holston River. This stream flows southwestward, in general hugging the foot of Pine Mountain, and its valley descends from an altitude of 2,000 feet at the northeast to 1,500 feet in the southwestern part of the area. The plateau to the southeast ranges from 2,000 to 2,500 feet in altitude and its surface is dissected into narrow transverse ridges and rounded hills.

## GEOLOGY.

### STRATIGRAPHY.

The rocks in which the deposits occur are of Mississippian ("Lower Carboniferous") age. A generalized section of the Carboniferous rocks derived from several detailed sections in the vicinity of the mines is as follows:

*Generalized section of Carboniferous rocks in the vicinity of Saltville, Va.*

| | Feet. |
|---|---|
| Newman limestone: | |
| Hard argillaceous limestone or calcareous shale, with a few beds of crystalline limestone | 800+ |
| Red calcareous sandstone and coarse crinoidal limestone, with some beds of argillaceous limestone | 75 |
| Light-blue argillaceous limestone and calcareous shale, with a few thicker pure fossiliferous limestones | 1,100 |
| Largely thick even-grained blue fossiliferous limestone, with some beds of crystalline fossiliferous limestone, argillaceous limestone, and calcareous shale; hard bed of conglomerate of limestone and shale fragments near middle | 1,350 |
| | 3,325+ |
| Maccrady formation: | |
| Earthy limestone and shale, dark gray, weathering lighter and crumbly, abundantly fossiliferous | 470± |
| Gray sandstone, mostly calcareous and crumbly, and shaly argillaceous or earthy limestone; fossiliferous at the top | 240 |
| Soft rocks, including shaly limestone and probably earthy sandstone and red shale, largely concealed | 225 |
| Upper part red shale and shaly sandstone, with some gray shaly sandstone; lower part soft light-buff shale, with thin black carbonaceous shale and coal seamlets | 90 |
| | 1,025± |

| | |
|---|---|
| Price sandstone: | |
| Hard irregular-bedded rusty-gray sandstone, with some heavier beds | Feet. 150–165 |
| Largely shaly sandstone, with a few harder beds | 150–205 |
| Massive gray to reddish-gray sandstone, thin bedded toward top, and fine conglomerate with scattered white quartz pebbles generally at base | 27– 54 |
| | 327–424 |
| Devonian rocks: | |
| Thin-bedded sandstone and sandy shale containing brachiopods of Chemung age | 536 |
| Platy sandstone and slaty shale. | |

The Price sandstone is a hard ridge-making rock which forms the ridge known as Pine Mountain and Brushy Mountain. The southeastern face of this ridge is a dip slope of the hard rocks of this formation, which dip about 40° SE. The severed edges of the dipping strata are finely exposed in the gaps through the mountain and make picturesque ledges and cliffs. Less well exposed in the gaps and on the northwest slope of the ridge are the underlying shaly sandstones and shales which are sparingly fossiliferous and of Chemung age. Fossils have not been obtained from the Price sandstone in this area, but the presence of coal seamlets near the top, its lithologic character, and its general stratigraphic position indicate its equivalence to the Pocono, at the base of the Carboniferous system. In the adjacent region to the northeast the Price sandstone contains thick coal beds whose flora establishes its Mississippian age.

The Maccrady formation is composed of materials relatively so soft and easily disintegrated that it is deeply eroded and in general poorly exposed. It outcrops in the valley of the North Fork of the Holston and is largely covered by the terrace and flood-plain deposits of that stream. The basal black shale and reddish sandy beds are not uncommonly exposed in the lower spurs of Pine Mountain, but the earthy limestones and shales of the formation are seen in few places. A few fossils have been found in some of the thin calcareous beds, and certain dark shales near the middle are in places highly fossiliferous. At the base are coal seamlets and underclays that carry plant remains. The invertebrates have been assigned by George H. Girty to the upper Mississippian, and he correlates the formation with the Moorefield shale of Arkansas. It also probably represents the lower part of the Mauch Chunk of Pennsylvania. In places plastic red and olive to bluish clays with gypsum deposits occur in the midst of the Maccrady formation. Their occurrence and relations are discussed under the heading "Origin of the deposits," on pages 248–249. This formation has been called the Pulaski shale in geologic reports describing adjacent areas to the northeast, and this name would be used here were it not that Pulaski has a prior established usage for an Ordovician formation in New York. The new name Maccrady is here given to the formation, from the village of that name on the North Fork of Holston River, where the best section of the formation was measured.

The Newman limestone is calcareous throughout but contains shaly portions which weather readily to clay and soil. The limestone generally makes hills, which in most places assume rounded forms due to dissection by streams flowing across the trend of the beds into the larger longitudinal streams. The formation is highly fossiliferous and the fauna indicates its general equivalence with the Greenbrier limestone of West Virginia and Pennsylvania and the Maxville limestone of Ohio.

Pre-Carboniferous rocks are present in two tracts within the area represented on the map (fig. 28). Beneath the basal Carboniferous sandstone lie Devonian sediments, mostly shales and sandstones, about 2,700 feet thick, underlain in turn by Silurian sediments, also mostly shales and sandstones. These are not differentiated on the map, as they do not concern the problems here discussed. These rocks occupy the northwestern portion of the mapped area and form the slopes of Clinch Mountain, which is capped by the basal Silurian formation, the Clinch sandstone, of Medina age.

In the southeastern part of the area mapped are Cambrian strata, mostly hard gray to blue magnesian limestone and dolomite, which are also undifferentiated on the map. The oldest of these Cambrian rocks are adjacent to the Carboniferous, with successively younger beds to the southeast.

## STRUCTURE.

The Cambrian rocks on the southeast are part of a great overthrust mass which rode on a flat fault plane over the Carboniferous strata on the northwest, as shown in the structure sections in figures 29 and 30. The Cambrian strata dip rather uniformly 30°–40° SE., successively older Cambrian strata appearing at the northwest. Massive gray dolomite and magnesian limestone of Cambrian age are adjacent to the fault throughout most of its course in the mapped area and probably form the competent strata that carried the thrust. There is no indication of an anticlinal axis in these lower limestones southwest of Saltville, where this formation has a narrow outcrop, but northeast of Saltville there is close folding in the broad belt of this formation adjacent to the fault, with all dips overturned to the southeast. A still lower Cambrian formation of red argillaceous shale and sandstone is exposed over part of this area. This folded portion of the Cambrian may represent the axis of an overturned anticline,

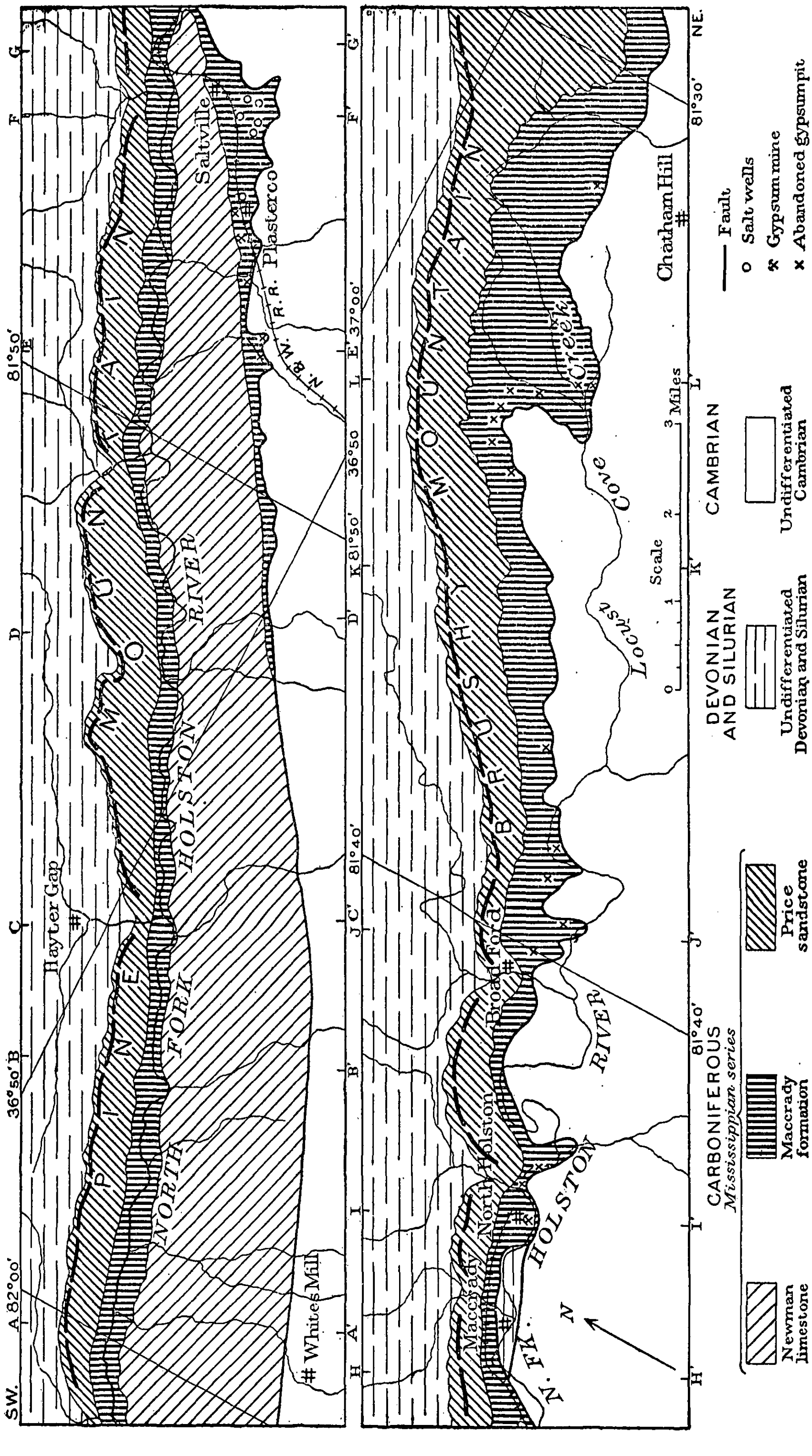



FIGURE 28.—Geologic map of Holston Valley in the vicinity of Saltville, Va. The crest of Pine and Brushy mountains is represented by a heavy broken line. Letters on margins indicate lines of sections in figures 29 and 30.

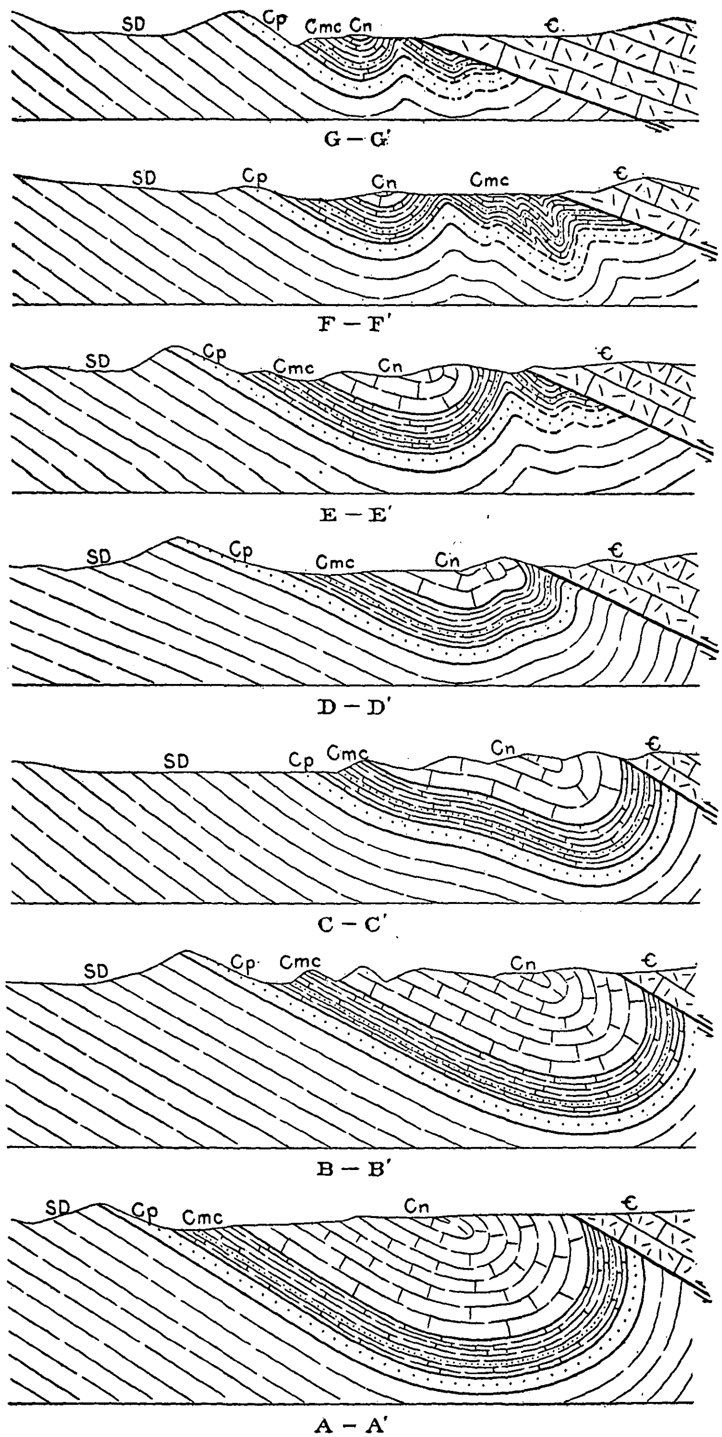



**FIGURE 29.**—Structure sections across Holston Valley along lines indicated by letters on the margins of the geologic map (fig. 28). Cn, Newman limestone; Cmc, Maccrady formation; Cp, Price sandstone; SD, undifferentiated Devonian and Silurian rocks; Є, undifferentiated Cambrian rocks, mostly dolomite. Scale, double the scale of figure 28.

the breaking and overthrusting of which initiated the faulting. This is no local or minor fault, however, for it has been traced throughout the southern Appalachians into the Rome fault, which has been demonstrated to have a horizontal displacement of at least 5 miles in the vicinity of Rome, Ga. A thrust fault of such magnitude and length must have a deep-seated origin and its plane may be a shear plane cutting diagonally across the strata, without folding except that produced by friction or drag.

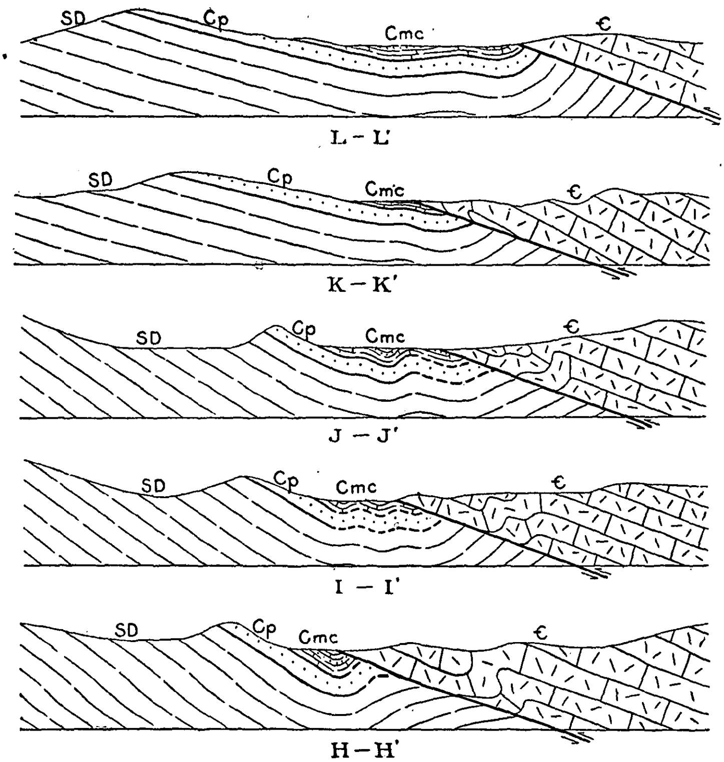



FIGURE 30.—Structure sections across Holston Valley along lines indicated by letters on the margins of the geologic map (fig. 28). Cn, Newman limestone; Cmc, Maccrady formation; Cp, Price sandstone; SD, undifferentiated Devonian and Silurian rocks; €, undifferentiated Cambrian rocks, mostly dolomite. Scale, double the scale of figure 28.

The fault plane is exposed at several places in the area, dipping southeast, and its inclination varies from 20° to 60°. Figure 31 is a sketch of the faulted rocks in the cliff west of Maccrady. Next to the fault plane the dolomite of the overthrust mass is hardened and the bedding obliterated, and the vertical beds farther from the plane of movement are jointed parallel to the plane. The softer shaly limestones beneath are mashed and altered by circulating waters to clay adjacent to the fault.

Another section of the fault laid bare by old gypsum workings 2 miles east of Broad Ford shows the Cambrian dolomite resting on red and green clay containing gypsum, with 1 foot of black banded carbonized calcareous clay gouge directly beneath the fault plane, which dips 20°–40° SE. In places a dolomite breccia of large and small masses marks the fault contact. In the railroad cut at Plasterco the cemented breccia is freshly exposed and its components are seen to be largely dolomite, with minor fragments of chert, limestone, and shale.

Opposite Maccrady Gap a mass of Clinch sandstone of Silurian age and associated rocks of sufficient size to make a hill 250 feet high and nearly 1 mile long was caught up along the fault and is shown on the map (fig. 28) by the fault dividing west of North Holston.

The outcrop of the fault plane is very crooked in the northeastern part of the area, owing to the fact that the plane is very flat in most places and is probably somewhat folded or wavy along the strike. Where the fault lies between the Cambrian dolomite and the shale of the Maccrady formation, it affords favorable channels for circulating underground water, from which springs issue at many places, and large solution channels are formed that may have aided in breaking down and removing the overlying dolomite at their outlets along the fault and may have assisted the formation of deep reentrants in the trace of the plane. These reentrants are invariably underlain by soft clays of the Maccrady formation, which form low flats generally without rock exposures. The reentrant at Saltville is one of the largest and is entirely barren of rock exposures. Another reentrant is at Broad Ford, where there are only a few outcrops of the lower harder beds in the Maccrady. Northwest of Chatham Hill is a still larger reentrant, due to the flattening of the general structure and a corresponding wider exposure of the softer rocks after being stripped of the overthrust Cambrian dolomite. These reentrant areas are the chief places where salt and gypsum deposits have been found and are of especial interest in the study of the distribution and origin of these products.

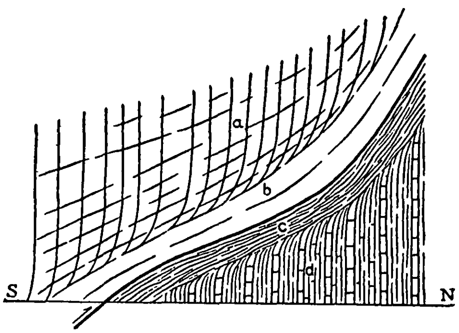



FIGURE 31.—Section of the faulted rocks in the cliff southwest of Maccrady, Va. a, Massive Cambrian dolomite, bedding vertical but indistinct, jointing parallel to fault; b, zone of altered dolomite, bedding entirely obliterated; c, zone of altered and crushed argillaceous material, banded parallel to the fault; d, earthy limestone and calcareous shale (Carboniferous).

The rocks northwest of the fault, except those immediately adjacent to it, lie in a monocline, dipping 25°–40° SE., which culminates in Clinch Mountain, northwest of the area mapped. The soft Carboniferous rocks near the fault are bent into an overturned syncline. The sections in figures 29 and 30 illustrate the progressive rise in this syncline from southwest to northeast. As the Newman limestone rises northward in the shallowing syncline, erosion has removed its upper portion and its remnant gradually diminishes in thickness from 3,300 feet in the most southern section until northeast of Saltville it is entirely absent. The soft underlying Maccrady formation does not extend all the way along the southeast side of the syncline but is faulted out in the southwestern part of the area. Where present on the southeast side it is vertical or overturned.

No outcrops are visible in the broad flat at Saltville, but the absence of hard outcropping strata and the record of only soft rocks of Maccrady type in the deep wells at this place indicate that the syncline is followed on the east by an anticline whose east limb carries the Price sandstone below the points reached by the drill but apparently not deep enough to bring the Newman limestone down to the surface, so on the sections the rocks are shown to be undulating in the portions under cover of the overthrust fault.

Northeast of Saltville the beds of the Maccrady formation are poorly exposed and their attitude is not generally shown. At the cliff west of Maccrady the last clear exposure of the syncline is preserved in the ledges of shale and sandstone. Just east of North Holston a small anticlinal roll of thin limestone in the Maccrady is an indication of the undulations probably existing throughout this band of soft rocks. East of Broad Ford a similar gentle fold is exposed in the small stream gully crossing the lowland.

Farther northeast the structure flattens more and more, and in the reentrant northwest of Chatham Hill a thin limestone in the Maccrady formation indicates a very gentle syncline, followed on the southeast by a gentle anticline and another syncline, which is sharply turned up at the fault. The gentle syncline is also shown in the southward swing of the Price sandstone outcrops forming Brushy Mountain at the northeast end of the area mapped.

From the overturned syncline of Newman limestone at the southwest it might at first be concluded that this was a syncline associated with an overturned anticline on the southeast, which broke and was thrust over upon the syncline. However, it is concluded from a wider study of the structure that the fault did not originate in a broken fold but is of deeper-seated origin, being manifest by a shear plane cutting diagonally across the strata and folding and crumpling those at the overridden contact by reason of friction and drag.

## SALT AND GYPSUM INDUSTRIES.

### SALT.

#### EARLIER DEVELOPMENT.

Salt seepages were known to exist in the vicinity of Saltville in pioneer days, for this swampy flat was one of the salt licks frequented by wild animals and was sought by hunters and trappers and before them by the Indians. The early settlers dug shallow wells and extracted the salt from the brine that flowed from the springs. As early as 1836 W. B. Rogers, then director of the Geological Survey of Virginia, reported two wells in operation, King's and Preston's, each 212 feet deep. The brine was conveyed 2 miles in wooden pipes, and after the crude impurities were allowed to settle in large tanks, it was treated in kettles, of which there were 500. About 30,000 gallons of brine were boiled down daily, yielding an average of 1,000 bushels of salt. The annual production is reported by Watson[1] to have been about 200,000 bushels. Calcium sulphate, almost the only impurity in the brine, adhered to the bottom of the kettles, thus purifying the product. The salt was reported free from chlorides of calcium and magnesium, or bittern. Three grades of salt were produced—common salt, fine grained but slightly discolored; table salt, white and fine, produced by rapid boiling; and alum salt, thin satiny crystals of great purity produced by slow crystallization as the kettles cooled. During the Civil War the wells at Saltville were the main source of salt for the Confederacy.

The first shaft in the Saltville flat was sunk in 1840. After passing through 20 feet of clay and 195 feet of red clay and gypsum it struck rock salt at a depth of 215 feet, the first definite proof of the existence of rock salt in this region. The salt was reported by the owner, the Holston Salt & Plaster Co., to continue to a depth of nearly 600 feet. As the shaft was dry it was abandoned as a brine producer, but it is stated that after a number of years the shaft was connected by a drift with an artesian well near by, the water from which, becoming saturated with salt, was pumped from the shaft.

The following analyses of rock salt, brine, and commercial salt from Saltville, showing their purity, are taken from T. L. Watson's report,[1] quoted from C. B. Hayden:

*Analyses of salt and brine from Saltville, Va.*

| | Rock salt. | Evaporated brine. | Commercial salt. | |
|---|---|---|---|---|
| NaCl | 99.084 | 97.792 | 98.540 | 98.146 |
| $CaCl_2$ | Trace. | .033 | .016 | .034 |
| $MgCl_2$ | | | | |
| $CaSO_4$ | .446 | 2.17 | 1.444 | 1.820 |
| $MgSO_4$ | | | | |
| $Al_2O_3$, $SiO_2$, and Fe | .470 | Trace. | | |

[1] Watson, T. L., Mineral resources of Virginia, Jamestown Exposition Com., 1907, p. 213.

Very little prospecting for salt seems to have been attempted beyond the Saltville area. Some borings have been made on the Robertson property, to the southwest, now leased by the United States Gypsum Co., but with what result is not known. Indications of brines have been reported at old gypsum workings to the northeast and at a depth of 300 feet in a shaft in the river bottom, presumably on the Cobbs farm. A well was reported to have been dug 500 feet deep for salt, before the Civil War, on the Buchanan property, 6 miles northeast of Broad Ford.

### PRESENT DEVELOPMENT.

The salt industry is now conducted by the Mathieson Alkali Works, with offices at Saltville. The Saltville Valley and surrounding country are owned and controlled by the company, and the town is well governed and kept clean, attractive, and wholesome. It has no superfluous stores, shops, houses, or churches; the houses are attractively built and have plenty of light, air, and yard; the public water supply is obtained from abundant springs protected from contamination; the town is illuminated by electricity.

Since 1895, when the Mathieson Co. came into control of the property, the brine has not been evaporated into salt, but is converted into other soda products, chiefly sodium bicarbonate, or baking soda, which is the basis of all baking powders and is used also to some extent in making soda water. A large part of the production is in the form of soda ash, used extensively in the manufacture of glass, pottery, etc. Sal soda is also made for this purpose. Caustic soda, put up in large hermetically sealed cans, is prepared for medicinal and other purposes.

Over 50 wells have been drilled in the vicinity of Saltville, about 25 of which are at present in operation. They range in depth from a few hundred feet to 2,280 feet, the average being about 1,000 feet. The shallower wells are on the northwest side of the flat and the deeper ones on the southeast side, near the fault. The former are dry wells and have to be flushed with water through the outer casing. The wells on the southeast side are wet and the brine flows in as fast as it is pumped out. In the wet wells the rocks become honeycombed and cave in, in some wells bending the pipe so as to cripple or entirely disable the well. The brine is raised by ordinary deep pumps each operated by a walking beam driven by an electric motor housed in a small shack at the well, and the brine is piped to an open reservoir in the town. From the reservoir it is piped to the company's plant covering several acres on the east bank of the North Fork of Holston River, about a mile distant, where it is converted into baking soda and the other sodium products.

For the conversion of salt to these compounds large quantities of pure calcium carbonate are used, and an aerial bucket tram carries crushed limestone from the company's quarry 3 miles southeast across the limestone hills. As the limestone must be free from magnesium and other impurities, satisfactory rock is difficult to obtain in quantity. Part of the present supply comes from quarries at Marion, Va., about 25 miles distant by rail on the main line of the Norfolk & Western Railway. About 600 tons is used daily.

### AMMONIA-SODA PROCESS.

The ammonia-soda or Solvay process is in general employed in the manufacture of bicarbonate of soda, but the details of method, process, and machinery used by the Mathieson Co. are not made public. The process in general is as follows:

The brine is first saturated with ammonia gas admitted through the perforated bottom of a tank and absorbed by the brine as it ascends through the liquid. The heat produced is taken up by coils of water-cooled pipes.

The saturated ammoniacal brine is pumped into tall carbonating tanks, and carbon dioxide is allowed to bubble through the liquor from a pipe near the bottom, the two being thoroughly mixed by means of a series of perforated diaphragms. As the brine from the Saltville wells is nearly free from iron, magnesium, and other impurities, except calcium, common to most brines, the reaction is not complicated by the presence of foreign elements. The reaction is $NaCl + NH_3 + H_2O + CO_2 = NH_4Cl + NaHCO_3$. The heat evolved in the chemical reaction is absorbed by water-cooled pipes or jacket. The bicarbonate of soda, being but slightly soluble in cold ammoniacal brine, is precipitated and settles slowly toward the bottom. The temperature must be carefully controlled to insure the best results, as some of the soda will remain in solution or the precipitate will be too fine to filter if the solution is too warm or too cold.

The thick milky liquid drawn off at the bottom contains admixtures of salt and ammonium chloride, and after filtration of the precipitate, or its concentration by centrifugal machines, these impurities are partly removed by washing the soda with water. The bicarbonate of soda is dried in a carbon dioxide atmosphere at about 90° C. and is ready for use as baking soda, except as it needs further refining and purifying.

To form soda ash, the acid bicarbonate is calcined in large pans or ovens, a process which also drives off any ammonia and water present. Heating $2NaHCO_3$ produces $Na_2CO_3 + CO_2 + H_2O$. This is generally a very pure sodium carbonate containing only a trace of salt and bicarbonate of soda and is entirely free from caustic soda, sulphide, or sulphate.

Soda crystal, or sal soda ($Na_2CO_3.10H_2O$), is produced by dissolving soda ash in warm water and crystallizing the clarified liquid by cooling in tanks. Large crystals of sal soda are formed which contain 60 per cent of water but are otherwise very pure, as the crystallization further purifies the product. A very pure bicarbonate may be obtained by exposing the sal soda crystals to a carbon dioxide atmosphere on a grating, the water being driven out and dropping through the grating, under the reaction $Na_2CO_3.10H_2O + CO_2 = 2NaHCO_3 + 9H_2O$.

Caustic soda (sodium hydroxide or hydrate) may be made from soda ash in solution by adding calcium hydroxide: $Na_2CO_3 + Ca(OH)_2 = CaCO_3 + 2NaOH$. The calcium carbonate is insoluble and precipitates as a lime mud. The sodium hydroxide is evaporated to dryness and is packed into hermetically sealed cans.

Saving the ammonia and carbon dioxide and avoiding the waste of by-products are essential in order to make the process profitable. The ammonia that escapes from the top of the carbonating tank and is removed from the bicarbonate in the process of purifying and calcining is saved by a special gas-collecting apparatus. The liquid in the carbonating tank after the bicarbonate is precipitated contains ammonium carbonate and sodium chloride, as well as ammonium chloride, and is passed through the ammonia still to extract and save the ammonia. Steam is admitted through the bottom and as it bubbles up through the liquid it decomposes the ammonium carbonate into ammonia, carbon dioxide, and water. The ammonium chloride settles to the bottom and is decomposed by calcium hydroxide, as follows: $2NH_4Cl + Ca(OH)_2 = CaCl_2 + 2H_2O + 2NH_3$. The calcium chloride remains in solution and is wasted.

Carbon dioxide for the soda process is obtained by burning limestone in kilns, the lime (CaO) being used in the manufacture of caustic soda. Part of the carbon dioxide is obtained in the calcination of the bicarbonate of soda. The limestone used in the process is largely converted back to lime mud in the caustic soda process and thus far has proved a waste. Attempts to briquet it for use in the roasters have not proved feasible and its waste is a great loss, amounting in the operations of the Mathieson Alkali Co. to several hundred tons daily. Some day a use will be found for this residual material and it will not only become a by-product, but the acres of lime mud now confined in settling ponds on the bottom lands will be a rich mine of pure calcium carbonate.

The following analyses of the limestone from the Mathieson Co.'s quarry are given by Watson:[1]

*Analysis of limestone from Mathieson quarry, 3 miles east of Saltville, Va.*

| | 1 | 2 |
|---|---|---|
| $CaCO_3$ | 97.03 | 96.73 |
| $MgCO_3$ | 1.24 | 1.37 |
| $SiO_2$, $Al_2O_3$, Fe | 1.64 | 1.80 |

## GYPSUM.

### EARLIER DEVELOPMENT.

Gypsum has been used for fertilizer for many years, and as early as 1835 Rogers mentioned the great possibilities of this deposit as a source of supply for the agricultural lands of Virginia. Over a decade ago gypsum was converted to plaster of Paris by roasting on only a small scale, as the product did not then have wide usage, but the adoption of this kind of plaster for walls in buildings, especially as a finishing coating, because of its superior hardness and whiteness, has made its production a large and profitable industry. When mixed with cement it acts as a retarder, greatly increasing the value of that product, and for gypsum to be used in this way there is now a large demand. As land plaster or fertilizer the gypsum is simply ground and not roasted. It has proved very beneficial to certain soils and for certain crops, being highly recommended for peanut cultivation.

Rogers in 1836 described these deposits as great detached masses of gypsum distributed along the Holston River belt for 40 miles. He reported an almost solid mass of gypsum 25 feet deep, 50 feet long, and 15 feet wide opened at McCall's quarry (probably one of the pits on the Robertson place), borings indicating that it extended to a depth of 100 feet, and stated that small openings had been made in the extensive exposures at the Buchanan banks in Walker Valley (Locust Cove), which indicated a great abundance of gypsum there.

Stevenson in 1885 reported extensive mining on the Robertson tract, at the southwest end of the Saltville Valley, where some large masses close to the surface had already been worked out. He also reported that plaster had been dug for five years to a depth of 60 feet at Pierson's (North Holston), 5 miles east of Saltville, and under the limestone bluff south of the river on the Miller farm; in a deep shaft in the river bottom on the Taylor farm, and in another shaft north of the road on the same property; and that extensive mining had been done by open pits and shafts on the Buchanan property, on Cove Creek, and in the small adjacent valley.

[1] Watson, T. L., op. cit., p. 214.

### PRESENT OPERATING MINES.

Two gypsum companies are operating in the area at the present time. The United States Gypsum Co., with offices in Chicago, leased the Robertson tract, adjoining the Mathieson Alkali Co.'s property on the southwest, from the Buena Vista Plaster Co. and has been operating for the last few years. This plant is located in a narrow extension of the broad flat at Saltville, separated from it by a low divide. Two shafts furnish access to the workings, which are reported to be about 100 feet below the surface, each set of workings seeming to be in a distinct body of gypsum. A third abandoned shaft leads to another mass of the deposit, and as other new bodies are located by drilling over the bottom land additional shafts will be sunk. Large deposits of gypsum on the eastern edge of the tract directly adjoining the Mathieson property were previously worked out by the owners.

As just mentioned, the gypsum in this mine seems to be in detached masses of great size and not in continuous beds, as might be expected. This will be referred to again later under the heading "Origin of the deposits." The gypsum is mostly a white to gray granocrystalline rock inclosed in clay, the gray variety streaked with fine dark argillaceous material. Numerous small anhydrite crystals are scattered through some of the gypsum from the old southernmost shaft, and these appear more prominently on weathered specimens. The gypsum is brought to the surface by elevators and conveyed by tram cars to the company's mill, where it is roasted and pulverized. The molding of plaster bricks, tiles, and hollow blocks in the company's shop is a new branch of the industry in this region.

The Southern Gypsum Co.'s plant and office are at North Holston, reached by the company's branch railroad from Saltville. The mine is on the old Pierson plaster-bank farm, in one of the embayments of lowland adjoining the North Fork of Holston River which is underlain by the soft shales of the Maccrady formation. The shaft in the lowland is connected by an aerial bucket tram with the main roasting and grinding plant at the railroad on the hillside. A large part of the crude product is ground for fertilizer at the lower mill near the shaft, much of the gypsiferous clay being of the right mixture to be used in this way for land plaster, effecting a great saving in the expense of mining. For wall and finishing plaster and cement retarder only the purer lump gypsum is employed.

The bulk of the gypsum here is much like that at the United States Co.'s plant, granular and crystalline. Some large sheets of pure selenite are encountered, and small veinlets of satin spar are common in the clay. Large masses of black argillaceous material called "black rock" occur in the midst of the gypsum, and apparent bedding of the gypsum is indicated by banding of black grains of the same material. The gypsum is reported to occur in beds of considerable thickness and extent and not in isolated masses, as at the United States Co.'s mine. The deposits have been tested by bore holes over all the river bottom of the embayment. The beds vary greatly in thickness, however, being somewhat lenticular in shape. The gypsum formerly outcropped at the river, where it was mined in open cuts in the early days for fertilizer. It is now mined from the shaft in the bottom land in all directions at a maximum depth of about 100 feet.

## OTHER PROSPECTS.

Old partly filled pits where gypsum, or "plaster," as it is commonly called, was mined from the surface in earlier days are still visible all along this belt from a point a mile west of Plasterco to the vicinity of Chatham Hill. Near Plasterco large pits, abandoned shafts, and caved-in ground abound, marking the places where the Buena Vista Co. and the Robertsons formerly operated extensively and removed much of the available gypsum that was close to the surface. Smaller openings were made in the embayment about 1 mile to the southwest, but the deposits there have been only slightly explored. They are all owned by the old Buena Vista Co. and are leased to the United States Gypsum Co. In the Saltville Valley thick deposits of gypsum are reported in all the wells drilled for salt, and some beds at the surface were formerly mined for the manufacture of a kind of cement. They are owned by the Mathieson Alkali Co. and are not now being worked.

At North Holston and in the embayment just east of it several old gypsum pits formerly worked on the Pierson and Miller farms are nearly obliterated. Several old pits are to be seen also near Broad Ford, some to the west but most of them in the broad embayment to the east. One is still open in the river bank on the Taylor farm, about a mile east of Broad Ford, where the gypsiferous shales have been dug out from beneath the overthrust Cambrian dolomite. Another pit on the Taylor farm is among the low hills to the northeast, beyond the point where the North Fork of Holston River leaves the belt of the Maccrady formation. A shaft on the adjacent Barnes place opened a large deposit by drifts but is now abandoned and filled with water.

Northeast of the Taylor farm conditions continue to appear favorable for the occurrence of gypsum, except that the exposed area of the Maccrady formation is narrow, but gypsum is not known to have been reported in the next 3 miles. Beyond, however, on the Buchanan property, important deposits occur and were mined on a large scale and crushed in the company's mill on the property, which was in operation three or four years ago and is still standing. The smaller holes have fallen in and been filled up, but some of the larger ones are full of water and are reported to be very deep. Pits are scattered over the broad embayment in the Maccrady formation, not only in the Locust Cove Creek bottom but also on the low divide and small valley to the west. Several pits were also located north of Chatham Hill, and the crude gypsum was crushed in a water-power mill on the river at Chatham Hill.

## ORIGIN OF THE DEPOSITS.

### FORMER VIEWS.

In his early description of these deposits W. B. Rogers correctly identifies the beds inclosing them as "Lower Carboniferous" and states further that they are at the fault contact between these beds and older limestones. As to their origin he adopts the explanation that oxidizing iron pyrites in the shales produced sulphuric acid, which, acting on limestone, converted it into calcium sulphate. He says:[1]

> In speculating upon the origin of the gypsum of this region, the readiest explanation that suggests itself is that which ascribes its production to similar causes with those which gave birth to the gypsum of the Tertiary strata of lower Virginia. It has been incidentally remarked above that pyritous slate occurs in fragments mingled with the gypsum and clay of the salt wells and other places. Supposing the valley to have once been filled with the débris of this slate and of the neighboring limestones, we would have all the materials brought together which are necessary for the production of the gypsum, while the slate after decomposition would become the clayey matrix in which the crystals would collect. This view is rendered more probable from the occurrence, even in the midst of the solid masses of plaster, of fragments of the siliceous rock which skirts the valley on the south. It is at least certain that the gypsum has not been deposited here, as in some other parts of the world, from the waters of thermal springs holding it in solution, since in that case it would be found disposed in layers as travertine and not in the irregular and scattered condition which has been described.

J. J. Stevenson,[2] in 1885, after describing the mining development, occurrence, and distribution of the gypsum and salt, arrives at somewhat similar conclusions, as follows:

> 1. The gypsum deposits are not beds of Carboniferous or Cambro-Silurian limestones changed into gypsum.
>
> 2. These deposits occupy deep basins, which have been eroded in Lower Carboniferous shale or limestone or in the hard, slightly calcareous sandstones of the Knox group. In at least two localities branches protrude from the main body into drains or ravines, so that the horizontal plan resembles somewhat the splash made by throwing soft mud against a wall.
>
> 3. The character of the deposit is wholly independent of the rocks on which it rests.

[1] Rogers, W. B., A reprint of annual reports * * * on the geology of the Virginias, 1884, pp. 141-142.
[2] Proc. Am. Philos. Soc., vol. 22, 1885, pp. 157-160.

4. The gypsum occurs in irregular masses, incased in red marly clay, which penetrates the gypsum to a variable distance; there is less of this clay in the eastern basins than at Saltville.

5. At a variable depth salt occurs with the gypsum, and this salt contains very little of iodides or bromides.

6. Blue clay overlies the gypsum at all localities yet examined.

7. No fossils of any sort have been found thus far in the gypsum, its incasing red clay, or in the overlying blue clay; but just west from Saltville a conglomerate cemented by gypsum occurs, in which remains of Mastodon have been found; this overlies the blue clay and incloses many fragments of both blue and red clay.

8. These gypsiferous deposits occur in the vicinity of the Saltville fault.

* * * * * * *

But the amount of the erosion and the general relation of the gypsum to the blue clay, with the relation of the latter to the Quaternary conglomerate, suggest that the gypsum is not older than the Tertiary; until some fossils have been discovered, however, the question of age must be regarded as undetermined.

* * * * * * *

Capellini ascribes the formation of this gypsum [at Castellina Marittima] to the action of sulphur springs on calcium carbonate held in solution; so that the carbonate was changed into sulphate and deposited as such in the littoral lakes of the middle Miocene. * * * The origin of the Holston gypsum is to be accounted for in some similar way. Several deep basins were occupied by lakes; that of the Saltville basin received not a little calcareous matter from the Lower Carboniferous beds forming its northerly shore, and some doubtless was received from the wash of the Knox beds on the southerly shore; in the basins farther east the calcareous matter derived from the wash should be far inferior to argillaceous matter. But the composition of the gypsum shows less of the red clay at Buchanan's than at Saltville. The principal source of the calcareous matter must be looked for not in the wash from the shores but in springs. That calcareous springs can produce deposits as extensive as those of this region is sufficiently shown by the extensive deposits around many of the springs at the far West. The calcium carbonate in solution would be converted into calcium sulphate by the sulphurous springs also issuing from the fault, and the gypsum would be deposited as such.

The red marly clays were derived from the wash and are more abundant at Saltville, where the soft red shales at the top of the Lower Carboniferous are fully exposed on the northerly side of the basin.

E. C. Eckel [1] in 1902 concluded that the deposits were interbedded as original sediments in the "Lower Carboniferous:"

Though the salt and gypsum deposits have been long known and worked and have been examined by many geologists, a wide range of opinion exists as to their age and origin, as will be seen on comparing the literature of the subject. It is sufficient in this place to note that, as to age, the deposits have been variously referred to the Silurian, Carboniferous, Triassic, Tertiary, and Pleistocene, while different authorities have considered them as originating from deposition from sea water, from deposition from lakes, by the decomposition of pyrite and resulting action on fragments of limestone, or by the action of sulphur springs on unweathered limestone.

The work of the last field season would seem to prove that both the salt and gypsum deposits originated from deposition, through the evaporation of sea water in a partly or entirely inclosed basin, and that they are of Lower Carboniferous age, being immediately overlain by the massive beds of the Greenbrier limestone and underlain by Lower Carboniferous sandstones.

[1] Bull. U. S. Geol. Survey No. 213, 1903, p. 406.

## OBSERVED RELATIONS.

The most striking fact in connection with the gypsum and salt deposits of this district is that they have been found in quantity only in the shales of the Maccrady formation along the Saltville fault. These shales also outcrop along the North Fork of the Holston southwest of Saltville, on the west side of the syncline, but so far as known neither gypsum nor salt has been observed in this area of the formation Stevenson reported gypsum on both sides of the fault on the Miller and Buchanan tracts northeast of Saltville, but these observations seem to be in error in that the fault was not accurately mapped, which is not strange, for the altered Carboniferous limestone very closely resembles the Cambrian dolomite, and some of the red shales of the Cambrian closely resemble those of the Carboniferous.

An effort has been made to obtain a carefully measured section of the Maccrady formation to determine the position of the gypsum and salt-bearing beds, but with scant success. In the broad flats where the gypsum occurs there are generally no outcrops except red clay and gypsum, and consequently there is little hope of solving the relation southwest of Saltville. Not even the base of the Maccrady, which is the most definite key horizon, is exposed there.

Northeast of Saltville there are a few good exposures, but generally where the gypsum occurs the inclosing rocks are soft clays and are hidden. The river cliff southwest of Maccrady is the best exposed section of these beds in the area, and the following details were measured there:

*Partial section of Maccrady formation west of Maccrady, Va.*

| | Thickness. | Distance above base. |
|---|---|---|
| | *Feet.* | *Feet.* |
| Dark crumbly fossiliferous shale and earthy gray limestones | 50± | |
| Alternate thick earthy limestone, calcareous shale, and thin crystalline fossiliferous limestones | 60 | 558 |
| Massive-bedded bluish tough calcareous and argillaceous sandstone with fossiliferous calcareous layers | 25 | |
| Gray sandstone, weathering brown | 5 | |
| Shaly earthy contorted sandy limestone | 31 | |
| Hard thick-bedded bluish calcareous sandstone | 20 | |
| Softer shaly earthy sandstone | 30 | |
| Thick bed of earthy sandstone | 6 | |
| Hard impure limestone, with chert nodules | 8 | |
| Thick soft earthy sandstone | 10 | |
| Shaly earthy limestone | 60 | |
| Thick-bedded to shaly earthy sandstone | 45 | 318 |
| Covered, probably some red shale, shaly earthy limestone, and soft earthy sandstone | 225± | 93 |
| Red shaly sandstone and shale, mottled yellow | 10 | |
| Red shale in part, rest covered | 25 | |
| Red shaly sandstone, mottled yellow | 7 | |
| Shaly gray sandstone, with phosphatic fish plates | 10 | |
| Sandy shale, in part covered | 20 | |
| Soft shale, light buff to dark drab; light-gray fire clay with rootlets, leaves, and twigs at base | 20 | |
| Black coaly fissile shale | 1 | |
| Slabby blue even-grained irregular-bedded sandstone, weathering buff (top of Price sandstone). | | |

The next best partial section is just east of Watson Gap, 2 miles southwest of Broad Ford, which is as follows:

*Partial section of Maccrady formation east of Watson Gap, Va.*

| | Thickness. | Distance above base. |
|---|---|---|
| | *Feet.* | *Feet.* |
| Thin-bedded earthy limestone, with some hard dense beds | 30 | 174 |
| Purple fissile shale, with some earthy limestones | 14 | |
| Fissile red shale | 10 | |
| Micaceous red sandstone, mottled yellow | 4 | |
| Fissile and crumbly red shale, mottled yellow | 37 | |
| Hard yellow and red agglomeratic shale | 1 | |
| Crumbly red sandstone and some yellow shale | 10 | 98 |
| Harder red sandstone, in part shaly | 4 | |
| Red argillite and shale, with drab sandy concretionary masses | 3 | |
| Greenish fire clay, with rootlets, red at surface | 2 | |
| Crumbly and fissile red and yellow shale | 30 | |
| Soft greenish micaceous sandstone, purplish at top | 20 | |
| Soft yellow shale | 4 | |
| Black fissile coaly shale | 3 | |
| Thin sandstone and fire clay, with rootlets | 1 | |
| Greenish fissile shale | 10 | |
| Thin irregular-bedded sandstone | 8 | |
| Sandy light-buff fire clay, with rootlets | 3 | |
| Covered, probably thin sandstone and shale | 10 | |
| Massive-bedded greenish-gray calcareous sandstone (top of Price sandstone). | | |

Just east of Broad Ford is another fair exposure that shows the relations of the gypsiferous shales to the rest of the formation:

*Partial section of Maccrady formation east of Broad Ford, Va.*

| | Thickness. | Distance above base. |
|---|---|---|
| | *Feet.* | *Feet.* |
| Soft red and green shale and clay, with some soft thick brown sandstone and earthy limestone; Red and green shale; Red rippled sandstone; Gray shale with red sandstone bed; Red shale and sandstone; Gray shale — Weather or change laterally into gypsum-bearing red plastic clays with secondary limestone layers | 150 | |
| Thin black fissile coaly shale | 1 | 182± |
| Earthy limestone and calcareous shale | 12 | 170± |
| Covered, probably in part soft earthy limestone | 40+ | |
| Red sandstone and sandy shale (with unexposed gray sandstone, shale, and carbonaceous seams to base of formation), estimated | 130± | |

From the relations observed in the northeastern part of the area it may be stated that the gypsum does not occur in the lower red siliceous beds of the formation and probably not lower than 180 feet from the base; that thin-bedded argillaceous limestones which are characterized by a small spirifer resembling *S. bifurcata* generally occur near the top of this barren interval; that the gypsum seems to replace certain soft earthy sandstones, shales, and limestones in the overlying portion of the formation present in that part of the area.

Southwest of Saltville, where the surface exposures do not show the relations of the gypsum, the well records also do not aid much in their solution. From a glance at the records of the Mathieson Alkali Co.'s borings, kindly permitted by Mr. W. D. Mount, manager of the plant, no clue was gained as to the sequence of the gypsum and salt beds or of their relation to recognizable limestone, sandstone, or hard red sandy beds. The basal barren sandy beds were not observed, even in the deepest well. A generalized record of one of the typical wells of the Mathieson Co. illustrates the relative distribution of the gypsum and salt which prevails throughout most of the sections.

*Generalized section of a well at Saltville, Va.*

| | Thickness. | Depth. |
|---|---|---|
| | *Feet.* | *Feet.* |
| Limestone and shale | 26 | 26 |
| Shale and gypsum | 195 | 221 |
| Mostly shale with gypsum and some rock salt | 359 | 580 |
| Mostly limestone with shale, gypsum, and rock salt | 215 | 795 |
| Mostly shale with gypsum and rock salt | 100 | 895 |
| Mostly rock salt with little shale | 197 | 1,092 |

The record of a well on the Buena Vista Plaster Co.'s property at Plasterco, as given by T. L. Watson, is as follows:

*Section of well at Plasterco, Va.*

| | Thickness. | Depth. |
|---|---|---|
| | *Feet.* | *Feet.* |
| Red clay | 10 | 10 |
| Clay and plaster | 6 | 16 |
| Impure plaster | 34 | 50 |
| Pure plaster | 52 | 102 |
| Slate and plaster | 63 | 165 |
| Nearly all plaster | 45 | 210 |
| Blue slate | 110 | 320 |
| Blue slate and plaster | 70 | 390 |
| Yellow soapstone | 55 | 445 |
| Pure plaster | 45 | 490 |
| Red rock with little salt | 15 | 505 |

The distribution of gypsum throughout several hundred feet of strata in the wells at Saltville and Plasterco indicates that, even if the beds have a relatively steep dip, the gypsum has a wide vertical range in the southwestern part of the area and may replace higher beds in the formation than occur at the surface in the northeast.

## CONCLUSIONS.

It can not be determined positively from the well records whether the deposits are in thick continuous beds or, as has been found to be the condition in the mines at Plasterco, in detached segregated masses. The distinct interbedding, however, of the gypsum with limestone, shale, red clay, and rock salt in the Saltville wells precludes the idea that the deposits were formed in wash from the surrounding higher areas into a trough or lake, as suggested by Stevenson. The gypsum beds have nowhere been mined deep or far enough to determine how they change laterally into other sedimentary rocks. This must be inferred from such facts as can be gathered in the mines, on the surface, and in the well records.

The conclusion expressed by Eckel that the deposits are strictly sedimentary in origin, having been derived from the evaporation of confined bodies of water under salt-pan conditions, is believed by the writer to be only partly correct. The fact that the beds of almost solid gypsum 50 to 100 feet in thickness vary greatly, occurring at intervals along the belt of these rocks, with barren areas between, and, so far as known, not at all on the northwest side of the syncline away from the fault, does not harmonize with this view. That salt-pan conditions could be so local and still persist for so long a time as to form such thick beds of gypsum and that these conditions could be repeated over and over again in the same place while not occurring at all in intervening areas is highly improbable.

The facts that the gypsum is segregated in workable deposits in the Maccrady formation at intervals along a fault contact, with barren areas between, and that none occurs in the same formation, so far as known, where not adjacent to the fault, are more reasonably explained by assuming, first, that gypsum was originally deposited as disseminated grains and innumerable thin leaves with argillaceous and calcareous silt and earthy sand of the Maccrady formation in a partly inclosed arm of the sea, at times subjected to intense evaporation; second, that the gypsum was later concentrated in the same formation by ground waters, which, circulating along the fault, dissolved part of the disseminated calcium sulphate and redeposited it in adjacent gypsiferous beds, the gypsum being segregated by chemical selection. The calcium carbonate in the calcareous silt was likewise dissolved by the meteoric waters and the gypsum has taken its place, possibly by direct replacement, the waters, being carbonated, dissolving the calcium carbonate and depositing the calcium sulphate.

A sample of unaltered earthy limestone from the Maccrady formation at the horizon of the gypsum-bearing clays was analyzed for F. A. Wilder, president of the Southern Gypsum Co., and was reported to contain 4 per cent of $CaSO_4$, which would represent the disseminated gypsum in an original calcareous silt.

In addition to the facts mentioned above pointing to this conclusion, several other observations may be cited. The occurrence of large crystalline sheets of selenite in the granocrystalline mass and especially of small veinlets of satin spar in the otherwise barren inclosing clay, affords positive proof that solution and redeposition may have taken place to some extent. The massive gypsum has the appearance of bedding, due to the banding of gray impurities, but on close observation this is found to be not sedimentary banding parallel to the inclosing strata but concentric banding parallel to inclosed bodies of "black rock," fine particles of the argillaceous material producing the dark banding. These argillaceous masses may have resulted from less soluble clayey masses in an otherwise calcareous gypsiferous bed which was gradually encroached upon during the concentration of the gypsum and particles of it were left as banded impurities in the gypsum; similar drab argillaceous concretionary masses were observed in the red argillite 94 feet above the base of the Maccrady formation on the road east of Watson Gap. Or, on the other hand, the argillaceous impurities may have been segregated in the rounded masses by chemical repulsion during the concentration and purification of the gypsum. At least, both the banding of the gypsum and the rounded masses of argillaceous "black rock" appear to have resulted from the secondary segregation of the gypsum. The red plastic clay that generally incloses the gypsum is probably the fine argillaceous impurity of the earthy limestone left as a residuum, expelled by the crystalline segregation of the gypsum, and stained red by contained iron highly oxidized when set free during the process. Thin layers of fine-grained limestone in the gypsiferous clays were apparently redeposited from solution as another secondary mineral.

This theory as to the method of the concentration of gypsum is not new, for it has been proved beyond much doubt that the remarkable domes of salt and gypsum in Louisiana and Texas were formed by the deposition of these minerals along spring lines at the exposed intersection of fissures or faults,[1] having been dissolved and transported from some deeper-lying beds. Secondary limestone, apparently similar to the crackled layers in the clays of the Holston Valley area, also occur in the domes associated with the salt and gypsum. The fact that the Louisiana deposits were derived from lower beds suggests the possibility that the salt and gypsum in the Holston Valley area were also derived from beds at a lower horizon, that the solutions rose along the fault, and that these minerals were deposited at or near the surface in their present position. This explanation, however, is untenable, inasmuch as none of the older formations which outcrop to the west on the slopes of Clinch Mountain—not even the representative of the Salina, the great salt and gypsum bearing formation of New York—contain deposits from which these minerals could have been derived, and furthermore, as such strictly secondary deposits would be found only at or near the surface, whereas the Holston Valley deposits occur interbedded in the Maccrady formation to considerable depths.

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[1] Harris, G. D., Rock salt: Bull. Louisiana Geol. Survey No. 7, 1907; Oil and gas in Louisiana: Bull. U. S. Geol. Survey No. 429, 1910.

If the theory of secondary concentration above suggested is the correct explanation of the origin of the gypsum in the Holston Valley area, it accounts for the absence of the mineral in quantity on the west side of the syncline away from the fault, the occurrence of natural outcrops of gypsum close to the fault, and the greater thickness of the deposits toward the southeast, as developed by borings in the Saltville, Plasterco, North Holston, and other tracts tested. In accordance with this theory it may be predicted that the gypsum will be found to extend under the overthrust Cambrian dolomite as far as the Maccrady formation is at the fault contact, and when the deposits near the surface are worked out deeper mining may be carried in this direction.

The beds of rock salt undoubtedly had the same origin as the gypsum and may be regarded as concentrations of somewhat saliferous beds, the associated calcium carbonate of the earthy limestone being dissolved out and its place taken by salt, segregated by solution and redeposition through chemical selection. Whether workable beds will be found associated with all the gypsum deposits can not at present be determined, but where salt has not been encountered in mining the gypsum there is still a prospect that it may be discovered at greater depth close to or under the overthrust dolomite. This is especially true southwest of Saltville, where the overriding Cambrian limestone conceals most of the Maccrady formation, as it is apparently turned under in a minor anticline next to the fault. Southwest of Plasterco both salt and gypsum may be expected along the fault some distance from its outcrop under the overthrust mass, where the Maccrady formation is probably at the fault contact. This may be proved by either drilling through an unknown thickness of tough dolomite southeast of the fault or boring diagonally under it in the soft rocks at the fault contact.

## SUMMARY.

The gypsum and salt deposits of southwestern Virginia described in this report are believed by the writer to have been derived from calcareous-argillaceous sediments which originally contained disseminated gypsum and salt precipitated in a partly inclosed arm of the sea during the deposition of the Maccrady formation, these minerals having been concentrated in the same formation by ground waters which circulated along the fault contact between the Carboniferous and Cambrian rocks, dissolved the calcium carbonate from the earthy limestones, and segregated the gypsum and salt in the gypsiferous and saline beds by chemical selection.

# SURVEY PUBLICATIONS ON BUILDING STONE AND ROAD METAL.

The following list comprises the more important recent publications on building stone and road metal by the United States Geological Survey. These publications, except those to which a price is affixed, can be obtained free by applying to the Director, United States Geological Survey, Washington, D. C. The priced publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C. The annual volumes on Mineral Resources of the United States contain not only statistics of stone production, but occasional discussions of available stone resources in various parts of the country. Many of the Survey's geologic folios also contain notes on stone resources that may be of local importance.


ALDEN, W. C., The stone industry in the vicinity of Chicago, Ill.: Bull. 213, 1903, pp. 357–360. 25c.

BAIN, H. F., Notes on Iowa building stones: Sixteenth Ann. Rept., pt. 4, 1895, pp. 500–503. $1.20.

BURCHARD, E. F., Structural materials available in the vicinity of Minneapolis, Minn.: Bull. 430, 1910, pp. 280–291.

——— Structural materials available in the vicinity of Austin, Tex.: Bull. 430, 1910, pp. 292–316.

——— Stone: Mineral Resources U. S. for 1911, pt. 2, 1912, pp. 741–834.

BUTTS, CHARLES, Variegated marble southeast of Calera, Shelby County, Ala.: Bull. 470, 1911, pp. 237–239.

COONS, A. T., Slate: Mineral Resources U. S. for 1911, pt. 2, 1912, pp. 723–739.

DALE, T. N., The slate belt of eastern New York and western Vermont: Nineteenth Ann. Rept., pt. 3, 1899, pp. 153–200. $2.25.

——— The slate industry of Slatington, Pa., and Martinsburg, W. Va.: Bull. 213, 1903, pp. 361–364. 25c.

——— Notes on Arkansas roofing slates: Bull. 225, 1904, pp. 414–416. 35c.

——— Note on a new variety of Maine slate: Bull. 285, 1906, pp. 449–450. Exhausted. May be found at large public libraries.

——— The granites of Maine: Bull. 313, 1907, 202 pp.

——— The chief commercial granites of Massachusetts, New Hampshire, and Rhode Island: Bull. 354, 1908, 228 pp.

——— The granites of Vermont: Bull. 404, 1909, 138 pp.

——— Supplementary notes on the granites of New Hampshire: Bull. 430, 1910, pp. 346–372.

——— Supplementary notes on the commercial granites of Massachusetts: Bull. 470, 1911, pp. 240–288.

——— The commercial marbles of western Vermont: Bull. 521, 1912, 170 pp.

DALE, T. N., and GREGORY, H. E., The granites of Connecticut: Bull. 484, 1911, 137 pp.

DALE, T. N., and others, Slate deposits and slate industry of the United States: Bull. 275, 1906, 154 pp. 15c.

DARTON, N. H., Marble of White Pine County, Nev., near Gandy, Utah: Bull. 340, 1908, pp. 377–380.

——— Structural materials in parts of Oregon and Washington: Bull. 387, 1909, 36 pp.

——— Economic geology of Richmond, Va., and vicinity: Bull. 483, 1911, 48 pp.

DILLER, J. S., Limestone of the Redding district, California: Bull. 213, 1903, p. 365. 25c.

ECKEL, E. C., Slate deposits of California and Utah: Bull. 225, 1904, pp. 417, 422. 35c.

GARDNER, J. H., Oolitic limestone at Bowling Green and other places in Kentucky: Bull. 430, 1910, pp. 373–378.

HILLEBRAND, W. F., Chemical notes on the composition of the roofing slates of eastern New York and western Vermont: Nineteenth Ann. Rept., pt. 3, 1899, pp. 301–305. $2.25.

HOPKINS, T. C., The sandstone of western Indiana: Seventeenth Ann. Rept.; pt. 3, 1896, pp. 780–787.

——— Brownstones of Pennsylvania: Eighteenth Ann. Rept., pt. 5, 1897, pp. 1025–1043.

HOPKINS, T. C., and SIEBENTHAL, C. E., The Bedford oolitic limestone of Indiana: Eighteenth Ann. Rept., pt. 5, 1897, pp. 1050–1057.

HUMPHREY, R. L., The fire-resistive properties of various building materials: Bull. 370, 1909, 99 pp. 30c.

KEITH, A., Tennessee marbles: Bull. 213, 1903, pp. 366–370. 25c.

LEIGHTON, HENRY, and BASTIN, E. S., Road materials of southern and eastern Maine: Bull. 33, Office of Public Roads, U. S. Dept. Agr., 1908. (May be obtained from Department of Agriculture.)

PAIGE, SIDNEY, Marble prospects in the Chiricahua Mountains, Arizona: Bull. 380, 1909, pp. 299–311.

——— Mineral resources of the Llano-Burnet region, Texas, with an account of the pre-Cambrian geology: Bull. 450, 1911, 103 pp.

PURDUE, A. H., The slates of Arkansas: Bull. 430, 1910, pp. 317–334.

RIES, HEINRICH, The limestone quarries of eastern New York, western Vermont, Massachusetts, and Connecticut: Seventeenth Ann. Rept., pt. 3 (continued), 1896, pp. 795–811.

SHALER, N. S., Preliminary report on the geology of the common roads of the United States: Fifteenth Ann. Rept., 1895, pp. 259–306. $1.70.

——— The geology of the road-building stones of Massachusetts, with some consideration of similar materials from other parts of the United States: Sixteenth Ann. Rept., pt. 2, 1895, pp. 277–341. $1.25.

SIEBENTHAL, C. E., The Bedford oolitic limestone [Indiana]: Nineteenth Ann. Rept., pt. 6, 1898, pp. 292–296.

SMITH, G. O., The granite industry of the Penobscot Bay district, Maine: Bull. 260, 1905, pp. 489–492. 40c.

UDDEN, J. A., The oolitic limestone industry at Bedford and Bloomington, Ind: Bull. 430, 1910, pp. 335–345.

WATSON, T. L., Granites of the southeastern Atlantic States: Bull. 426, 1910, 282 pp.

# SURVEY PUBLICATIONS ON CEMENT AND CEMENT AND CONCRETE MATERIALS.

The following list includes the principal publications on cement materials by the United States Geological Survey or by members of its staff. The Government publications, except those to which a price is affixed, can be obtained free by applying to the Director, United States Geological Survey, Washington, D. C. Applications for publications marked with an asterisk (*) should be addressed to the United States Bureau of Standards at Washington. The priced publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C.


Adams, G. I., and others, Economic geology of the Iola quadrangle, Kansas: Bull. 238, 1904, 80 pp. 25c.

Ball, S. H., Portland cement materials in eastern Wyoming: Bull. 315, 1907, pp. 232–244.

Bassler, R. S., Cement materials of the valley of Virginia: Bull. 260, 1905, pp. 531–544. 40c.

Burchard, E. F., Portland cement materials near Dubuque, Iowa: Bull. 315, 1907, pp. 225–231.

——— Concrete materials produced in the Chicago district: Bull. 340, 1908, pp. 383–410.

——— Structural materials available in the vicinity of Minneapolis, Minn.: Bull. 430, 1910, pp. 280–291.

——— Structural materials available in the vicinity of Austin, Tex.: Bull. 430, 1910, pp. 292–316.

——— The cement industry in the United States in 1911: Mineral Resources U. S. for 1911, pt. 2, 1912, pp. 485–519.

Butts, Charles, Sand-lime brick making near Birmingham, Ala.: Bull. 315, 1907, pp. 256–258.

——— Ganister in Blair County, Pa.: Bull. 380, 1909, pp. 337–342.

Catlett, C., Cement resources of the valley of Virginia: Bull. 225, 1904, pp. 457–461. 35c.

Clapp, F. G., Limestones of southwestern Pennsylvania: Bull. 249, 1905, 52 pp.

Crider, A. F., Cement resources of northeast Mississippi: Bull. 260, 1905, pp. 510–521. 40c.

——— Geology and mineral resources of Mississippi: Bull. 283, 1906, 99 pp.

Darton, N. H., Geology and water resources of the northern portion of the Black Hills and adjoining regions in South Dakota and Wyoming: Prof. Paper 65, 1909, 104 pp.

——— Structural materials in parts of Oregon and Washington: Bull. 387, 1909, 36 pp.

——— Cement materials in Republican Valley, Nebraska: Bull. 430, 1910, pp. 381–387.

DARTON, N. H., and SIEBENTHAL, C. E., Geology and mineral resources of the Laramie Basin, Wyoming: Bull. 364, 1908, 81 pp.

DURYEE, E., Cement investigations in Arizona: Bull. 213, 1903, pp. 372–380. 25c.

ECKEL, E. C., The materials and manufacture of Portland cement: Senate Doc. 19, 58th Cong., 1st sess., 1903, pp. 2–11.

——— Cement-rock deposits of the Lehigh district: Bull. 225, 1904, pp. 448–450. 35c.

——— Cement materials and cement industries of the United States: Bull. 243, 1905, 395 pp. Exhausted. Available for reference in larger public libraries.

——— The American cement industry: Bull. 260, 1905, pp. 496–505. 40c.

——— Portland cement resources of New York: Bull. 260, 1905, pp. 522–530. 40c.

——— Cement resources of the Cumberland Gap district, Tennessee-Virginia: Bull. 285, 1906, pp. 374–376. Exhausted. Available for reference in larger public libraries.

——— Portland cement materials of the United States, with contributions by E. F. Burchard and others: Bull. 522 (in press).

ECKEL, E. C., and CRIDER, A. F., Geology and cement resources of the Tombigbee River district, Mississippi-Alabama: Senate Doc. 165, 58th Cong., 3d sess., 1905, 21 pp.

FENNEMAN, N. M., Geology and mineral resources of the St. Louis quadrangle, Missouri-Illinois: Bull. 438, 1911, 73 pp.

*HUMPHREY, R. L., The effects of the San Francisco earthquake and fire on various structures and structural materials: Bull. 324, 1907, pp. 14–61. 50c.

*——— Organization, equipment, and operation of the structural-materials testing laboratories at St. Louis, Mo.: Bull. 329, 1908, 85 pp.

*——— Portland cement mortars and their constituent materials: Results of tests, 1905 to 1907: Bull. 331, 1908, 130 pp. 25c.

*——— The strength of concrete beams; results of tests made at the structural-materials testing laboratories: Bull. 344, 1908, 59 pp. 10c.

*——— The fire-resistive properties of various building materials: Bull. 370, 1909, 99 pp. 30c.

LANDES, H., Cement resources of Washington: Bull. 285, 1906, pp. 377–383. Exhausted. May be seen at many public libraries.

MARTIN, G. C., The Niobrara limestone of northern Colorado as a possible source of Portland cement material: Bull. 380, 1909, pp. 314–326.

PEPPERBERG, L. J., Cement material near Havre, Mont.: Bull. 380, 1909, pp. 327–336.

RICHARDSON, G. B., Portland cement materials near El Paso, Tex.: Bull. 340, 1908, pp. 411–414.

RUSSELL, I. C., The Portland cement industry in Michigan: Twenty-second Ann. Rept., pt. 3, 1902, pp. 620–686. $2.

*SEWELL, J. S., The effects of the San Francisco earthquake on buildings, engineering structures, and structural materials: Bull. 324, 1907, pp. 62–130. 50c.

SHAW, E. W., Gravel and sand in the Pittsburg district, Pennsylvania: Bull. 430, 1910, pp. 388–399.

SMITH, E. A., The Portland cement materials of central and southern Alabama: Senate Doc. 19, 58th Cong., 1st sess., 1903, pp. 12–23.

——— Cement resources of Alabama: Bull. 225, 1904, pp. 424–447. 35c.

TAFF, J. A., Chalk of southwestern Arkansas, with notes on its adaptability to the manufacture of hydraulic cements: Twenty-second Ann. Rept., pt. 3, 1902, pp. 687–742.

# SURVEY PUBLICATIONS ON CLAYS, ETC.

In addition to the papers named below, some of the publications listed on pages 258–259 and certain of the geologic folios contain references to clays.

These publications, except those to which a price is affixed, can be obtained free by applying to the Director, United States Geological Survey, Washington, D. C. The priced publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C. The publications marked "Exhausted" are no longer available for distribution but may be consulted at the larger libraries of the country.


ALDEN, W. C., Fuller's earth and brick clays near Clinton, Mass.: Bull. 430, 1910, pp. 402–404.

ASHLEY, G. H., Notes on clays and shales in central Pennsylvania: Bull. 285, 1906, pp. 442–444. Exhausted.

ASHLEY, H. E., The colloid matter of clay and its measurement: Bull. 388, 1909, 65 pp.

BASTIN, E. S., Clays of the Penobscot Bay region, Maine: Bull. 285, 1906, pp. 428–431. Exhausted.

BRANNER, J. C., Bibliography of clays and the ceramic arts: Bull. 143, 1896, 114 pp. 15c.

——— The clays of Arkansas: Bull. 351, 1908, 247 pp.

BUTTS, CHARLES, Clays of the Birmingham district, Alabama: Bull. 315, 1907, pp. 291–295. 50c.

CRIDER, A. F., Clays of Western Kentucky and Tennessee: Bull. 285, 1906, pp. 417–427. Exhausted.

DARTON, N. H., Geology and water resources of the northern portion of the Black Hills and adjoining regions in South Dakota and Wyoming: Prof. Paper 65, 1909, 106 pp.

——— Economic geology of Richmond, Va., and vicinity: Bull. 483, 1911, 48 pp.

DARTON, N. H., and SIEBENTHAL, C. E., Geology and mineral resources of the Laramie Basin, Wyoming; a preliminary report: Bull. 364, 1909, 81 pp.

DEUSSEN, ALEXANDER, Notes on some clays from Texas: Bull. 470, 1911, pp. 302–352.

ECKEL, E. C., Stoneware and brick clays of western Tennessee and northwestern Mississippi: Bull. 213, 1903, pp. 382–391. 25c.

——— Clays of Garland County, Ark.: Bull. 285, 1906, pp. 407–411. Exhausted.

FENNEMAN, N. M., Clay resources of the St. Louis district, Missouri: Bull. 315, 1907, pp. 315–321. 50c.

——— Geology and mineral resources of the St. Louis quadrangle, Missouri-Illinois: Bull. 438, 1911, 73 pp.

FISHER, C. A., The bentonite deposits of Wyoming: Bull. 260, 1905, pp. 559–563. 40c.

——— Clays in the Kootenai formation near Belt, Mont.: Bull. 340, 1908, pp. 417–423.

FULLER, M. L., Clays of Cape Cod, Massachusetts: Bull. 285, 1906, pp. 432–441. Exhausted.

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LINES, E. F., Clays and shales of the Clarion quadrangle, Clarion County, Pa.: Bull. 315, 1907, pp. 335–343. 50c.

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[1] Previous volumes of the Mineral Resources of the United States contain chapters devoted to clay and the clay-working industries of the United States.

## SURVEY PUBLICATIONS ON GYPSUM AND PLASTERS.

The more important publications of the United States Geological Survey on gypsum and plasters are included in the following list. These publications, except those to which a price is affixed, can be obtained free by applying to the Director, United States Geological Survey, Washington, D. C. The priced publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C. The publications marked "Exhausted" are no longer available for distribution but may be consulted at the larger libraries of the country.


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# SURVEY PUBLICATIONS ON GLASS SAND AND GLASS-MAKING MATERIALS.

The list below includes the important publications of the United States Geological Survey on glass sand and glass-making materials. These publications, except those to which a price is affixed, can be obtained free by applying to the Director, United States Geological Survey, Washington, D. C. The priced publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C. The publications marked "Exhausted" are no longer available for distribution but may be consulted at many public libraries.


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Stose, G. W., Glass-sand industry in eastern West Virginia: Bull. 285, 1906, pp. 473–475. Exhausted.

Weeks, J. D., Glass materials: Mineral Resources U. S. for 1883–84, 1885, pp. 958–973, 60c.; idem for 1885, 1886, pp. 544–555, 40c.

## SURVEY PUBLICATIONS ON LIME AND MAGNESITE.

In addition to the papers listed below, which deal principally with lime, magnesite, etc., further references on limestones will be found in the lists given under the heads "Cement" and "Building stone." These publications, except the one marked "Exhausted," can be obtained free by applying to the Director, United States Geological Survey, Washington, D. C.

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RIES, HEINRICH, The limestone quarries of eastern New York, western Vermont, Massachusetts, and Connecticut: Seventeenth Ann. Rept., pt. 3, 1896, pp. 795–811.

# ASPHALT.

## SURVEY PUBLICATIONS ON ASPHALT.

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VAUGHAN, T. W., The asphalt deposits of western Texas: Eighteenth Ann. Rept., pt. 5, 1897, pp. 930–935

# ABRASIVES.

## SURVEY PUBLICATIONS ON ABRASIVE MATERIALS.

The following list includes a number of papers, published by the United States Geological Survey or by members of its staff, dealing with various abrasive materials. The Government publications, except those to which a price is affixed, can be obtained free by applying to the Director, United States Geological Survey, Washington, D. C. The priced publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C.

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RABORG, W. A., Buhrstones: Mineral Resources U. S. for 1886, 1887, pp. 581–582. 50c.

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