# White Clays of Pennsylvania

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*By* JOHN W. HOSTERMAN

CONTRIBUTIONS TO THE GEOLOGY OF MINERAL DEPOSITS

GEOLOGICAL SURVEY BULLETIN 1558-D

*Geology and geologic setting of
white clays*

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CONTRIBUTIONS TO THE GEOLOGY OF MINERAL DEPOSITS

# WHITE CLAYS OF PENNSYLVANIA

### By JOHN W. HOSTERMAN

#### ABSTRACT

The white clays of Pennsylvania are composed chiefly of kaolinite and various amounts of illite. Most of the white clays are silty and a few are sandy. Quartz or chert is the only nonclay mineral in the whitest material; goethite is also present in the colored samples high in iron. The average alumina content is slightly more than 20 percent in samples from three clay pits and less than 15 percent in samples from five clay pits. The white clay deposits are found in eastern, south-central, and central Pennsylvania. They occur in rocks of the Appalachian basin that range in age from Cambrian to Devonian; however, their age of formation is Cretaceous or later. Some of the deposits are the result of katamorphic alteration, and some are the result of weathered material being transported and deposited in sinkholes or caverns. The presence of alunite in one deposit suggests the possibility that the clay may be the result of both katamorphic and hydrothermal alteration.

## INTRODUCTION

White clay in Pennsylvania was first mined in about 1890 for use in the paper industry as a paper filler and paper coater. The State continued to be a leader in production of white clay until 1930. However, with the introduction into the market of better quality clays from the Southeastern States, white clay in Pennsylvania lost its importance in the paper industry.

White clays are being mined or have been mined from near Mount Holly Springs in Cumberland County; near Kunkletown in Monroe County; several deposits in Centre, Huntingdon, and Blair Counties; near Dillsburg in York County; and Narvon in Lancaster County (fig. 1). The clays are currently used in making white portland cement, refractory products, and as a carrier for insecticides and fungicides. They have also been used for face brick in the past.

**White Clay Deposits**

1. Kunkletown
2. Narvon
3. Dillsburg
4. Toland: Near Mount Holly Springs
5. Stormstown
6. Alexandria
7. Oreminea

FIGURE 1.—Index map showing location of white clay deposits in Pennsylvania.

Most of the clays are light gray (N8) to white (N9), but some are stained yellow, pink, or brown by iron oxides. Kaolinite is the predominant clay mineral, but illite is as abundant as kaolinite in the deposits at Kunkletown, Narvon, and Dillsburg. The quartz or chert content averages 30 percent in the Mount Holly Springs deposit, about 45 percent in the Kunkletown and Stormstown deposits, and 50 percent or more in the other deposits; however, within each deposit, the amounts differ considerably.

The white clays were considered by previous workers (Stose, 1907, p. 324; Peck, 1922, p. 3; and Leighton, 1934, p. 1) to be residual deposits derived by weathering of feldspathic sandstone, argillaceous and cherty limestones, and phyllites. The present investigation has found that deposits near Kunkletown, Narvon, and Alexandria are residual (derived by chemical weathering in place), which is also known as katamorphic alteration. The deposit near Mount Holly Springs is also the result of katamorphic alteration, but the presence of alunite indicates the possibility of hydrothermal alteration. The clay deposit near Dillsburg probably has the same geologic history as the one near Mount Holly Springs. The morphology of the clay deposits of Centre, Blair, and Bedford Counties in the Gatesburg Formation indicates that they are composed of weathered debris deposited in caves or sinkholes.

The purpose of this investigation was to study the geology and mineralogical and chemical composition of the white clay deposits in Pennsylvania. Knowledge of the deposits will contribute to a better understanding of white clay resources and may be helpful in determining potential uses for the clay. In addition, knowledge about the origin of the clay deposits and a study of the parent material will help determine whether the abandoned clay pits can be used for waste disposal.

## METHODS OF INVESTIGATION

A review was made of the published geologic literature. The areal geology of the clay deposit discussed is based on the work of several geologists. Stose (1953) and Freedman (1967) mapped the vicinity of Mount Holly Springs; Epstein and Epstein (1967) mapped the area around Kunkletown, and the geologic map of Pennsylvania (Gray and others, 1960) was the primary source of geologic information for all other clay deposits.

Auger-drilling equipment was used to sample the clay deposits. This equipment consisted of a power auger mounted on the back of a 2-ton truck. The drilling method consisted of sampling a 1.5-m interval at a time and pulling the auger from the hole after each interval. This was repeated until the desired depth of sampling was reached.

When the auger was pulled from the hole after each interval, a sample was taken from between the whorls of the leading auger flights. A 1.5-m interval usually filled almost two auger flights with material. The sample was disturbed, but contamination from the walls of the hole was easily cut away from the outside.

The mineralogical and chemical composition of the samples was determined in the laboratory by means of X-ray diffraction and X-ray fluorescence methods described in an earlier report (Hosterman, 1969a, p. 6 and 7). The whole rock samples were ground to minus 170 mesh. The powder was pressed into a pellet 28 mm in diameter in an evacuated hydraulic press for a minimum of 30 seconds at a pressure of 30,000 pounds per square inch (psi). A 50-50 mixture of boric acid and methyl cellulose was pressed beneath the sample in the mold for support. The clay fraction was obtained by placing a portion of the sample in water and allowing it to settle for 2 hours and 3 minutes. The suspended material in the upper 10 centimeters was carefully siphoned off; this material contained the clay fraction of less than 4 micrometers ($\mu$m) in diameter. An oriented aggregate was obtained by sedimenting the clay fraction onto a porous ceramic tile and removing the water by vacuum. The ratios of clay, silt, and sand were calculated on the basis of dry-weight percentages. Sand was removed by means of a No. 230 sieve, and then clay was removed from silt by repeated washings. The description of all the samples, in this report, is based on the system of sediment nomenclature in Hosterman (1969a, fig. 2).

The X-ray diffraction method for mineralogical identification and X-ray fluorescence method for chemical composition are routine. The X-ray diffraction method consisted of using $CuK\alpha_1$ radiation (1.54050 A) with a diffraction beam monochromator. Most clay samples were treated in several ways and examined by X-ray diffraction after each treatment so that various clay minerals could be detected. Samples were treated with ethylene glycol to identify expandable clay (smectite) and were heated to 300°C to identify collapsible clay (mixed-layer clay or vermiculite). Several samples were treated with $3N$ hydrochloric acid to check for the presence of chlorite and kaolinite. The clay mineral ratios are based on peak-area ratios obtained from the X-ray diffraction traces. On the basis of reproducibility tests, this procedure provides a method for determining the amount of each mineral present to an accuracy of about ±10 percent. The limestone samples were dissolved by heating samples in a 20-percent solution of acetic acid to concentrate the insoluble material and make identification easier. The X-ray fluorescence method consisted of using a Cr-target tube for primary radiation with a lithium fluoride analyzing crystal ($2d$=4.0267 A) for iron and

titanium and with a pentaerythritol analyzing crystal ($2d$=8.78 A) for calcium, potassium, silicon, and aluminum. All elements are reported as oxides, and total iron is reported as $Fe_2O_3$. This method is not as accurate as the wet-chemical method, but it is found to be accurate within 10 percent of the amount of oxide present.

Representative samples from six clay deposits were tested for their potential value as paper clays by the Georgia Kaolin Co. The brightness, measured as a percentage, was determined by means of a reflection meter or brightness tester. The minimum requirement of a paper-grade clay is a brightness of at least 80 percent for use as a paper filler and at least 85 percent for use as a paper coater. The viscosity, in centipoises, is measured with a viscometer in which a Brookfield No. 3 spindle is used. The viscosity should be less than 500 centipoises, but occasionally a viscosity of between 500 and 700 centipoises is acceptable as a paper filler (H. H. Murray, oral commun., April 1970).

## ACKNOWLEDGMENTS

## CLAY DEPOSITS NEAR KUNKLETOWN AND SAYLORSBURG, MONROE COUNTY

### LOCATION AND HISTORY

White silty clay deposits occur between Kunkletown and Saylorsburg, Monroe County, Pa. (fig. 1). The clay deposits currently mined are about 1.6 km southeast of Kunkletown. The first clay mining near Kunkletown began before 1900 when clay from the north side of Chestnut Ridge was used in making soap. Later, white brick was made at Kunkletown by the New York and Pennsylvania Brick and Tile Co. and, still later, by the Chestnut Ridge White Clay Co. In 1932, the Atlas Portland Cement Co. and its successor, the Universal Atlas Cement Co., moved its operation to near Kunkletown from the north slope of Cherry Ridge, where clay had been mined

since 1909. The clay pits currently provide 200 tons of raw material per day (Epstein and Hosterman, 1969, p. D94). The clay is trucked 22 miles to Northampton where it is ground, made into a slurry, and blended into a kiln feed used in making white portland cement.

White clay near Saylorsburg was first mined in 1891 when Oscar Drehr built a plant to make enameled brick. In 1894, the Blanchard brothers of Newark, N.J., took over the plant and made dry pressed brick. Fourteen years later in 1908, the Keystone Clay and Reduction Co. began operating a plant to produce washed white clay (Peck, 1922, p. 2). By 1919, this company was producing about 30 tons of washed clay per day (Leighton, 1941, p. 185). The white clay was used chiefly as a paper filler, and a minor amount was used in the manufacture of rubber and paint. In 1917, the Mt. Eaton Clay Co., which later became the Pennsylvania White Clay Mining Co., began operating a pilot plant and mine 2.4 km southeast of Saylorsburg on the north slope of Chestnut Ridge. During the 1920's, this plant produced 50 tons of clay per day. The clay was dried, ground, and sold as a refractory material for use in foundries and blast furnaces (Leighton, 1941, p. 186). The last company to produce clay at Saylorsburg was the Blue Ridge Clay Co.; however, no clay mining has been active in this area since the mid-1930's.

## GEOLOGY

The clay deposits are the weathered material of a heterogeneous assemblage of Upper Silurian through Middle Devonian limestones, shales, siltstones, sandstones, and dolomites. Unweathered outcrops of these rocks, west of Bossardsville, Pa., are rare, whereas fresh rocks crop out in abundance northeast of Bossardsville and have been described by Epstein and Epstein (1967). The weathered part of the rocks or saprolite is probably more than 30.5 m thick in many places, and a hole drilled by the cement company penetrated 55.5 m of clay without striking fresh rock (G. F. Smith, oral commun., 1969).

Clay has been and is currently being mined from weathered parts of the New Scotland Formation, Shriver Chert of the Oriskany Group, and Buttermilk Falls Limestone. Where fresh, these rocks are generally cherty, silty, argillaceous limestones and limy shales. They have been weathered to silty clays and clayey silts. The best quality clays are white to yellowish gray, but some are stained various shades of pink and orange. In some of the deposits, the chert has not been completely leached and remains as hard nodules. The formations that weather to clay become thinner and less pure (less calcareous and more siliceous and iron stained) westward, and the clay west of Little Gap is too low grade and has never been mined.

The thickest deposits occur in the Saylorsburg area where they have been extensively worked (Peck, 1922). No clay deposits have been found east of Bossardsville and the Wisconsin terminal moraine. Thus, the most promising areas for the prospecting are about 3.2 km east of the presently active area where pit operations should prove most profitable, and between Kunkletown and about 1.6 km west of Saylorsburg, where underground workings might be considered.

The clay-bearing units crop out in long narrow belts and are repeated by folding (fig. 2). Two of the pits are confined to near the top of the ridge where overburden is not a great problem. The third pit along the side of the ridge has an overburden of Palmerton Sandstone, which is mined for sand. Underground mining has not been attempted recently as it once was near Saylorsburg (Peck, 1922).

## COMPOSITION

The mineralogy of fresh bedrock samples and equivalent weathered rock samples was studied to determine the changes that took place as a result of katamorphic alteration. The unweathered rocks, on which the clays are developed, are chiefly argillaceous limestones and limy shales. Carbonate minerals and quartz make up most of these rocks, and chlorite and $2M$ illite are the dominant clay minerals. Illite was found to be only a minor constituent in samples of fresh Buttermilk Falls Limestone, but it is abundant in the rocks weathered from the limestone. Kaolinite, which is very abundant in the weathered rocks, was not identified in the fresh, unweathered rocks. Quartz or chert is the only other mineral present with illite and kaolinite in all the weathered material; chlorite, calcite, and dolomite have been replaced owing to katamorphic alteration. The overall chemical average of the weathered rocks (table 1), as determined by X-ray fluorescence methods, is similar to the average raw material used by the Universal Atlas Cement Co. from the pits near Kunkletown: 80.8 percent $SiO_2$, 12.1 percent $Al_2O_3$, 0.6 percent $Fe_2O_3$, 0.6 percent CaO, and 0.3 percent MgO (G. F. Smith, oral commun., September 1967).

Clay tests published by Ries and others (1922, p. 115) show that clay from near Kunkletown has an approximate drying shrinkage of 3 percent, a fired linear shrinkage of 3 to 12 percent, and absorption of about 10 percent. The fact that no statement was made about the workability indicates that it is probably poor. The paper-grade tests of a representative composite sample showed a brightness of 57.6 percent. The viscosity, tested on samples containing 71 percent solids, is 160 and 255 centipoises at 10 and 100 revolutions per minute, respectively.

Base from Universal Atlas Cement Division of United States Steel
Corporation, Kunkletown, Pennsylvania,1961. Compiled from aerial
photographs by Fairchild Aerial Surveys, 1952
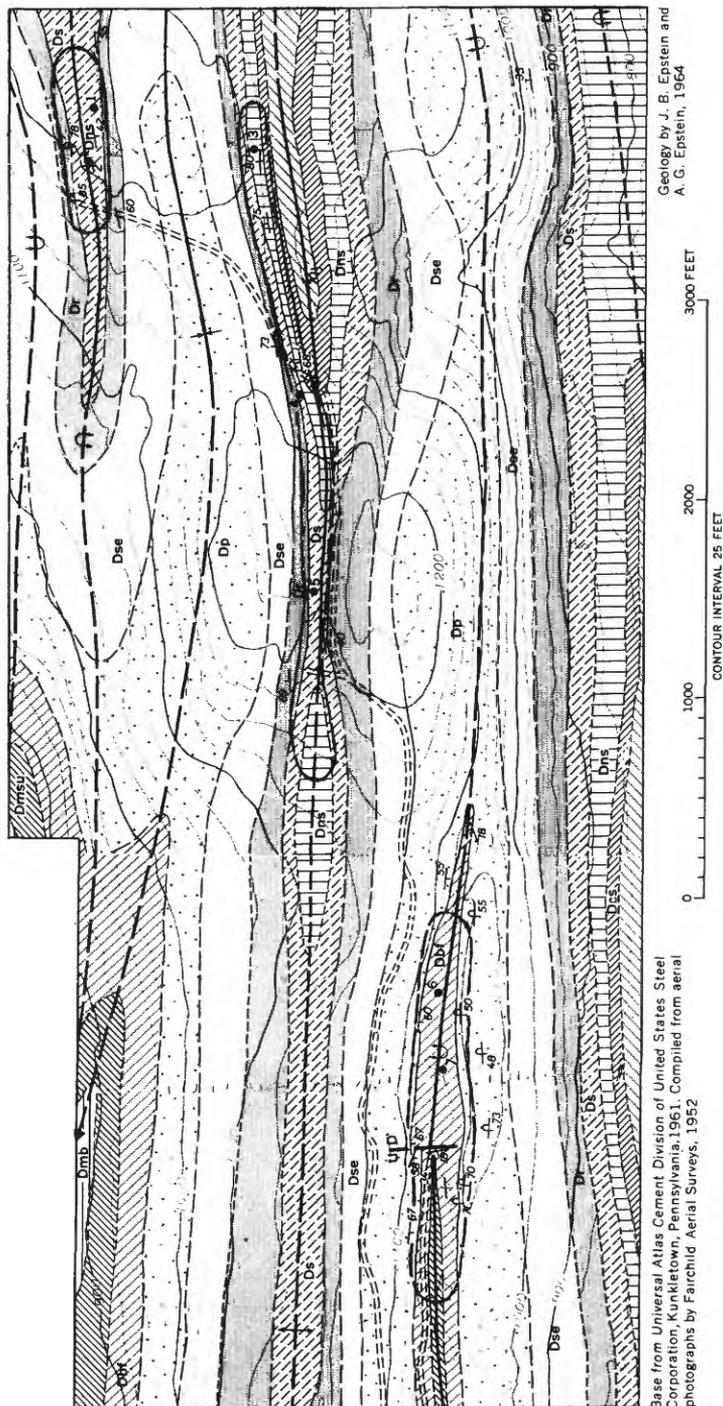
Geology by J. B. Epstein and
A. G. Epstein, 1964

CONTOUR INTERVAL 25 FEET

0      1000      2000      3000 FEET

EXPLANATION

**Lower Devonian**

Dns — New Scotland Formation

Dcs — Stormville Member of Coeymans Formation

DEVONIAN

Contact
Long dashed where approximately located; short dashed where inferred

Fault
U, upthrown side; D, downthrown side

Anticline
Showing trace of axial surface and direction of plunge. Long dashed where approximately located; short dashed where inferred

Syncline
Showing trace of axial surface and direction of plunge. Long dashed where approximately located; short dashed where inferred

**Middle Devonian**

Dmb — Dmsu — Marcellus Shale
Dmb, Brodhead Creek Member
Dmsu, Stony Hollow and Union Springs Members, undifferentiated

Dbf — Buttermilk Falls Limestone

Dp — Palmerton Sandstone

Dse — Schoharie and Esopus Formations, undivided

**Lower Devonian**

Dr — Ds — Oriskany Group
Dr, Ridgely Sandstone
Ds, Shriver Chert

DEVONIAN

Overturned anticline
Showing trace of axial surface and direction of dip of limbs and plunge. Long dashed where approximately located; short dashed where inferred

Overturned syncline
Showing trace of axial surface and direction of dip of limbs and plunge. Long dashed where approximately located; short dashed where inferred

Inclined   Vertical   Overturned
Strike and dip of beds

Auger hole

Clay deposit

N

FIGURE 2.—Geologic map of the Universal Atlas Cement Co. clay pits on Chestnut Ridge, approximately 6.4 km north-northeast of Kunkletown, Pa., and location of auger holes described in table 1. Modified from Epstein and Hosterman, 1969.

TABLE 1.—*Chemical and mineralogical composition of residual silty clay from the Atlas clay pits near Kunkletown, Monroe County*

| Description | Depth (meters) | Moisture (percent) | Chemical analyses[1] (percent) | | | | | | | | Grain-size distribution (percent) | | | Clay minerals[2] (ratio) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | $K_2O$ | $TiO_2$ | Loss on ignition 1,000°C | Sum | Sand | Silt | Clay | Kaolinite | Illite |
| **Auger hole 1** | | | | | | | | | | | | | | | |
| Shriver Chert saprolite[3]: | | | | | | | | | | | | | | | |
| Silty clay (N9) | 0.3 | 18.9 | 78 | 13 | 0.7 | 0.2 | 2.5 | 0.7 | 4.6 | 99.7 | 7 | 36 | 57 | 4.5 | 5.5 |
| Silty clay (10YR9/1) | .6 | 7.6 | 76 | 14 | .9 | .2 | 3.1 | .8 | 4.6 | 99.6 | 4 | 43 | 53 | 4.5 | 5.5 |
| Silty clay (10YR8/1) | 1.5 | 12.3 | 78 | 13 | .6 | .2 | 2.7 | .7 | 4.2 | 99.4 | 5 | 40 | 55 | 4.5 | 5.5 |
| Do | 3.0 | 13.8 | 76 | 14 | .7 | .2 | 3.1 | .9 | 3.4 | 98.3 | 4 | 39 | 57 | 4 | 6 |
| Do | 4.5 | 14.3 | 78 | 14 | .7 | .2 | 2.7 | .8 | 3.1 | 99.5 | 5 | 36 | 59 | 5 | 5 |
| Do | 6.0 | 14.8 | 79 | 13 | .7 | .2 | 2.8 | .8 | 2.9 | 99.4 | 3 | 36 | 61 | 5 | 5 |
| Do | 7.5 | 16.2 | 75 | 16 | .8 | .2 | 3.6 | .9 | 3.5 | 100.0 | 3 | 34 | 63 | 4.5 | 5.5 |
| Do | 9.5 | 15.9 | 76 | 15 | .8 | .3 | 3.5 | .9 | 3.5 | 100.0 | 3 | 38 | 59 | 4.5 | 5.5 |
| Sandy silty clay (10YR8/1) | 11.0 | 13.3 | 84 | 10 | .5 | .4 | 1.9 | .6 | 2.1 | 99.5 | 18 | 34 | 48 | 4.5 | 5.5 |
| **Auger hole 2** | | | | | | | | | | | | | | | |
| New Scotland Formation saprolite: | | | | | | | | | | | | | | | |
| Silty clay (5Y9/1) | 1.5 | 13.0 | 78 | 14 | 0.7 | 0.2 | 3.1 | 0.7 | 3.2 | 99.9 | 5 | 38 | 57 | 4.5 | 5.5 |
| Do | 3.5 | 14.3 | 77 | 15 | .7 | .2 | 3.3 | .9 | 3.3 | 100.4 | 4 | 39 | 57 | 5 | 5 |
| Do | 4.5 | 10.7 | 78 | 14 | .7 | .2 | 3.2 | .8 | 3.3 | 100.2 | 8 | 41 | 51 | 4.5 | 5.5 |
| Do | 6.0 | 15.6 | 77 | 15 | .7 | .2 | 3.2 | .8 | 2.8 | 99.7 | 6 | 36 | 58 | 4.5 | 5.5 |
| Silty clay (5Y9/2) | 7.5 | 9.0 | 77 | 14 | .8 | .2 | 3.3 | .9 | 3.1 | 99.3 | 8 | 29 | 63 | 4.5 | 5.5 |
| Silty clay (5Y9/1) | 9.0 | 10.5 | 80 | 13 | .6 | .2 | 2.8 | .8 | 2.7 | 100.1 | 7 | 36 | 57 | 5 | 5 |
| Silty clay (5R7/2) | 10.5 | 14.0 | 78 | 12 | 2.5 | .3 | 2.9 | .8 | 2.8 | 99.3 | 9 | 35 | 56 | 6 | 4 |
| Silty clay (10R7/1) | 12.0 | 16.7 | 76 | 14 | 2.1 | .3 | 3.4 | .9 | 2.9 | 99.5 | 5 | 35 | 60 | 6 | 5 |
| Silty clay (10YR8/3) | 16.0 | 15.1 | 75 | 14 | 2.2 | .3 | 3.6 | .8 | 3.7 | 99.6 | 6 | 34 | 60 | 5 | 5 |
| Silty clay (2.5Y9/2) | 18.5 | 14.4 | 74 | 16 | 1.1 | .2 | 4.1 | .9 | 4.1 | 100.4 | 4 | 33 | 63 | 4 | 6 |
| Silty clay (2.5Y8/2) | 20.5 | 11.9 | 72 | 16 | 2.0 | .2 | 4.4 | .9 | 3.7 | 99.2 | 5 | 36 | 59 | 4 | 6 |
| Silty clay (5Y9/1) | 24.5 | 15.5 | 73 | 16 | .7 | .2 | 4.0 | .9 | 4.0 | 98.8 | 5 | 34 | 61 | 4 | 6 |
| Do | 27.5 | 16.1 | 75 | 15 | .7 | .3 | 3.7 | .9 | 3.8 | 99.4 | 7 | 32 | 61 | 4 | 6 |
| Do | 30.5 | 14.7 | 77 | 14 | .7 | .4 | 3.4 | .8 | 3.4 | 99.7 | 8 | 31 | 61 | 3 | 7 |

**Auger hole 3**

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| New Scotland Formation saprolite: | | | | | | | | | | | | | | |
| Silty clay (N9) | 3.0 | 9.6 | 78 | 14 | 0.5 | 0.3 | 3.0 | 0.7 | 3.3 | 99.8 | 6 | 43 | 51 | 4 | 6 |
| Do | 6.0 | 7.7 | 80 | 12 | .5 | .3 | 2.5 | .6 | 3.9 | 99.8 | 6 | 44 | 50 | 4 | 6 |
| Silty clay (5Y9/1) | 9.0 | 12.1 | 74 | 16 | .8 | .3 | 3.8 | .9 | 4.4 | 100.2 | 9 | 37 | 54 | 4 | 6 |
| Stormville Member of Coeymans Formation: | | | | | | | | | | | | | | |
| Sand, yellowish-brown | 9.1 | --- | | | | | | | | | | | | |

**Auger hole 4**

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Shriver Chert saprolite: | | | | | | | | | | | | | | |
| Sandy, silty clay (7.5Y9/1) | 3.0 | 8.6 | 89 | 6.7 | 0.3 | 0.4 | 1.2 | 0.3 | 1.9 | 99.8 | 26 | 36 | 38 | 5 | 5 |
| Clayey silt (7.5Y9/1) | 6.0 | 10.1 | 87 | 8.4 | .6 | .4 | 1.5 | .4 | 1.9 | 100.2 | 18 | 50 | 32 | 5 | 5 |
| Clayey silt (7.5Y9/2) | 7.5 | 9.4 | 87 | 7.8 | .6 | .4 | 1.4 | .4 | 2.2 | 99.8 | 15 | 50 | 35 | 5 | 5 |

**Auger hole 5**

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Shriver Chert saprolite: | | | | | | | | | | | | | | |
| Clayey silt (N9) | 3.0 | 4.8 | 88 | 8.0 | 0.3 | 0.2 | 1.6 | 0.4 | 1.6 | 100.1 | 14 | 48 | 38 | 4 | 6 |
| Do | 6.0 | 7.9 | 86 | 8.9 | .4 | .2 | 1.9 | .4 | 2.1 | 99.9 | 16 | 44 | 40 | 4 | 6 |
| Silty clay (7.5Y9/1) | 9.0 | 9.0 | 81 | 11.0 | .5 | .1 | 2.6 | .7 | 2.6 | 98.5 | 11 | 44 | 45 | 4 | 6 |
| Do | 12.0 | 12.9 | 77 | 14.0 | .7 | .2 | 3.3 | .8 | 3.6 | 99.6 | 8 | 39 | 53 | 3.5 | 6.5 |
| Do | 15.0 | 12.6 | 73 | 16.0 | .8 | .4 | 3.9 | .9 | 4.7 | 99.7 | 3 | 39 | 58 | 3 | 7 |
| Clayey silt (7.5Y9/2) | 17.0 | 10.5 | 82 | 11.0 | .8 | .4 | 2.1 | .5 | 2.4 | 99.2 | 16 | 42 | 42 | 4 | 6 |

**Auger hole 6**

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Buttermilk Falls Limestone saprolite: | | | | | | | | | | | | | | |
| Clayey silt (N9) | 2.5 | 9.2 | 80 | 13.0 | 0.4 | 0.4 | 3.0 | 0.7 | 2.9 | 100.4 | 2 | 52 | 46 | 4 | 6 |
| Silty clay (N9) | 4.5 | 16.7 | 73 | 17.0 | .7 | .3 | 4.2 | .9 | 4.2 | 100.3 | 1 | 37 | 62 | 4.5 | 5.5 |
| Silty clay (7.5Y9/1) | 7.5 | 15.2 | 84 | 9.8 | .3 | .3 | 2.1 | .5 | 2.4 | 99.4 | 2 | 46 | 52 | 4 | 6 |
| Do | 10.5 | 17.7 | 84 | 10.0 | .3 | .3 | 2.2 | .5 | 2.7 | 100.0 | 4 | 44 | 52 | 4.5 | 5.5 |
| Silty clay (10YR7/3) | 13.5 | 14.7 | 75 | 15.0 | 1.6 | .2 | 3.7 | .9 | 3.4 | 99.8 | 3 | 33 | 64 | 4.5 | 5.5 |
| Silty clay (7.5Y9/1) | 17.0 | 15.2 | 74 | 16.0 | .7 | .4 | 4.0 | .9 | 3.9 | 99.9 | 2 | 28 | 70 | 4 | 6 |
| Palmerton Sandstone saprolite: | | | | | | | | | | | | | | |
| Sandy, silty clay (7.5Y9/1) | 19.5 | 9.9 | 84 | 9.0 | .7 | .4 | 2.1 | .5 | 2.3 | 99.0 | 33 | 24 | 43 | 5 | 5 |

TABLE 1.—*Chemical and mineralogical composition of residual silty clay from the Atlas clay pits near Kunkletown, Monroe County*—Continued

| Description | Depth (meters) | Moisture (percent) | Chemical analyses[1] (percent) | | | | | | | | Grain-size distribution (percent) | | | Clay minerals[2] (ratio) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | SiO₂ | Al₂O₃ | Fe₂O₃ | CaO | K₂O | TiO₂ | Loss on ignition 1,000°C | Sum | Sand | Silt | Clay | Kaolinite | Illite |
| **Auger hole 7** | | | | | | | | | | | | | | | |
| Buttermilk Falls Limestone saprolite: | | | | | | | | | | | | | | | |
| Silty clay (N9) | 3.0 | 14.3 | 85 | 9.2 | 0.2 | 0.3 | 1.9 | 0.5 | 2.1 | 99.2 | 3 | 45 | 52 | 5 | 5 |
| Do | 5.0 | 12.5 | 90 | 6.2 | .2 | .3 | .9 | .3 | 1.5 | 99.4 | 18 | 40 | 42 | 6 | 4 |
| Do | 6.0 | 10.8 | 81 | 12.0 | .2 | .3 | 1.9 | .3 | 3.6 | 99.3 | 3 | 34 | 63 | 7 | 3 |
| Do | 9.0 | 18.1 | 87 | 8.4 | .1 | .1 | 1.3 | .4 | 1.9 | 99.2 | 3 | 47 | 51 | 5.5 | 4.5 |
| Do | 12.0 | 19.5 | 85 | 9.4 | .3 | .2 | 1.8 | .5 | 2.3 | 99.5 | 16 | 31 | 53 | 5 | 5 |
| Silty clay (5Y 9/1) | 15.0 | 18.4 | 82 | 11.0 | .9 | .4 | 2.4 | .6 | 2.5 | 99.8 | 2 | 37 | 61 | 4.5 | 5.5 |
| Silty clay (7.5Y 9/1) | 18.5 | 21.1 | 73 | 16.0 | .9 | .3 | 4.1 | .9 | 4.4 | 99.6 | 2 | 27 | 71 | 3.5 | 6.5 |
| Silty clay (5Y 9/2) | 19.0 | 25.7 | 76 | 14.0 | 1.0 | .3 | 3.5 | .9 | 4.0 | 99.7 | 1 | 25 | 74 | 3 | 7 |
| Palmerton Sandstone saprolite: | | | | | | | | | | | | | | | |
| Sandy, silty clay (7.5YR 8/2) | 20.0 | 17.6 | 79 | 12.0 | 1.9 | .4 | 2.8 | .7 | 2.7 | 99.5 | 22 | 21 | 57 | 3.5 | 6.5 |
| Sand, brown | 21.5 | --- | | | | | | | | | | | | | |
| **Averages** | | | | | | | | | | | | | | | |
| New Scotland Formation: saprolite (17 samples) | | 13.0 | 76 | 14 | 1.1 | 0.2 | 3.4 | 0.8 | 3.4 | 98.9 | 6 | 36 | 58 | 4.5 | 5.5 |
| Shriver Chert saprolite (18 samples) | | 11.0 | 81 | 12 | .6 | .3 | 2.4 | .6 | 2.9 | 99.8 | 11 | 41 | 48 | 4.5 | 5.5 |
| Buttermilk Falls Limestone saprolite (14 samples) | | 16.2 | 80 | 12 | .6 | .3 | 2.7 | .6 | 2.9 | 99.1 | 4 | 38 | 58 | 4.5 | 5.5 |
| All units | | 13.4 | 79 | 13 | .8 | .3 | 2.9 | .7 | 3.1 | 99.8 | 7 | 38 | 55 | 4.5 | 5.5 |

[1] Chemical analyses by X-ray fluorescence methods.

[2] Based on X-ray diffraction peak-area ratios; 7.1 A basal peak for kaolinite and 10.0 A basal peak for illite.

[3] Color designations are based on the "Munsell Soil Color Chart" (Munsell Color Co., 1954).

## NARVON CLAY PIT, LANCASTER COUNTY

The clay pit near Narvon, in eastern Lancaster County, 6.4 km west of Honeybrook, lies along the north slope of Welsh Mountain. Welsh Mountain is underlain by the resistant Chickies Quartzite of Late Proterozoic age. The upper part of the Chickies is composed of thin-bedded siltstone and argillite that weathers to a yellowish-gray and light-gray clayey silt. The deposit was first discovered in 1875 by a railroad crew and has been mined almost continuously from two pits since 1880. The property is presently owned by the Narvon Mines, Ltd. The clayey silt produced was dried, ground, and bagged and sold for use in filler materials, ceramics, insecticide carriers, and water purification.

Seven samples were taken vertically at 1.5-m intervals from the west face of the pit; the first sample was taken 3 m below the soil overburden. The clayey silt is composed of approximately 8 percent sand, 62 percent silt, and 30 percent clay (table 2). Quartz is the predominant mineral in the sand and silt fractions, and the clay fraction is composed of kaolinite and illite in a 7:3 ratio. A paper-grade test of a composite sample from the pit showed a brightness of 73 percent. The viscosity, tested on samples containing 71 percent solids, is 1,500 and 913 centipoises at spindle speeds of 10 and 100 revolutions per minute, respectively. The silty clay is not a paper-grade material and, according to Leighton (1934, p. 15), does not have the properties of china clay.

## CLAY PIT NEAR DILLSBURG, YORK COUNTY

The clay pit 3.4 km west of Dillsburg (fig. 1) is in an eastern extension of the same geologic setting as the clay pits near Mount Holly Springs. According to Leighton (1934, p. 14) and Stose (1953), the deposit is residual clay derived from the Harpers Schist. However, it is probably a residual weathered phyllite of the Tomstown Formation. The Tomstown is composed of thick-bedded, dense, bluish-gray dolomite, light-gray thin-bedded limestone, and light-gray phyllite. The thickness of the formation is difficult to calculate because exposures are very rare. Freedman (1967, p. 37) estimated its thickness to be about 300 m. The Tomstown is the youngest unit in the immediate area. It is underlain, from youngest to oldest, by the Antietam Quartzite, the Montalto Quartzite Member of the Harpers Schist, and the Weverton Quartzite. These formations are Late Proterozoic to Early Cambrian in age (Stose, 1953).

On the basis of 11 samples (table 3) collected from the surface of the pit and from a 15-m auger hole, the material has an average grain-size composition of clayey silt. The color ranges from a pale

TABLE 2.—*Chemical and mineralogical composition of residual clayey silt from the Narvon pit, Lancaster County*

| Description | Depth (meters) | Moisture (percent) | Chemical analyses[1] (percent) | | | | | | | | Grain-size distribution (percent) | | | Clay minerals[2] (ratio) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | $K_2O$ | $TiO_2$ | Loss on ignition 1,000°C | Sum | Sand | Silt | Clay | Kaolinite | Illite |
| **West face of pit:** | | | | | | | | | | | | | | | |
| Clay silt (10YR8/1)[3] ............ | 3.0 | 8.7 | 67 | 19 | 2.2 | 0.3 | 3.3 | 1.6 | 5.7 | 99.1 | 12 | 57 | 31 | 6.5 | 3.5 |
| Do ................................. | 4.5 | 11.6 | 65 | 21 | 2.5 | .1 | 3.1 | 1.1 | 5.8 | 98.6 | 7 | 61 | 32 | 7.5 | 2.5 |
| Do ................................. | 6.0 | 10.0 | 64 | 21 | 2.8 | .2 | 3.8 | 1.1 | 5.7 | 98.6 | 4 | 67 | 29 | 7.5 | 2.5 |
| Do ................................. | 7.5 | 8.7 | 65 | 21 | 2.5 | .2 | 3.4 | 1.2 | 6.8 | 100.1 | 6 | 66 | 28 | 7.5 | 2.5 |
| Do ................................. | 9.0 | 10.6 | 69 | 19 | 1.9 | .3 | 2.8 | 1.2 | 5.7 | 99.9 | 11 | 60 | 29 | 8 | 2 |
| Clayey silt (N8) ............... | 10.5 | 14.6 | 63 | 21 | 2.6 | .1 | 4.4 | 1.0 | 5.6 | 97.7 | 4 | 62 | 34 | 7 | 3 |
| Do ................................. | 12.0 | 11.1 | 67 | 21 | 2.0 | .1 | 3.5 | 1.0 | 5.7 | 100.3 | 9 | 64 | 27 | 7 | 3 |

[1] Chemical analyses by X-ray fluorescence methods.
[2] Based on X-ray diffraction peak-area ratios; 7.1 A basal peak for kaolinite and 10.0 A basal peak for illite.
[3] Color designations are based on the "Munsell Soil Color Chart" (Munsell Color Co., 1954).

yellow to a weak yellowish orange owing to an iron oxide content that ranges from 1 to 24 percent (table 3). Kaolinite and illite occur in a ratio of approximately 7:3. Quartz makes up the silt and sand fractions, and goethite is abundant enough in some samples to make it almost an iron ore. The deposit has very little value economically, except possibly in making red building or face brick. It is presently owned by the Boy Scouts of America, York-Adams Area Council, who operate a summer camp nearby.

## CLAY DEPOSITS NEAR MOUNT HOLLY SPRINGS, CUMBERLAND COUNTY

### LOCATION AND HISTORY

As many as five white clay deposits in the vicinity of Mount Holly Springs have been worked during the past 75 years. The only one being worked and available for sampling at present is the open pit at Toland owned by the Philadelphia Clay Co.

All the abandoned clay deposits and the deposit at Toland are south and southwest of Mount Holly Springs in a narrow valley enclosed by two parallel southwest-trending ridges. The two ridges, Piney Mountain and South Mountain, are the northern extension of the Blue Ridge Mountains, which extends from Pennsylvania to Georgia.

White clay deposits in the South Mountain area have been mined intermittently since about 1890, but no accurate production data are available. The clay was probably first recognized in the mid-1800's by prospectors looking for iron ore. Between 1890 and 1910, at least five companies mined clay in the area. Four of these companies had facilities for beneficiating the clay that was sold for use as a paper filler. One company in Mount Holly Springs used the raw clay for making cream to light-buff brick (Stose, 1907, p. 330). By 1930, however, only two companies were mining clay: the Philadelphia Clay Co. had a 100-ton daily capacity mill for washing and drying clay, and the Medusa Portland Cement Co. was mining and shipping raw clay for use as a whitener in portland cement (Leighton, 1934, p. 13). By the mid-1960's, the Philadelphia Clay Co. was the only producer of clay. This company, using earth-moving equipment, has changed from underground to open-pit mining and is currently producing about 40,000 tons of raw clay a year for use as a whitener in portland cement.

### GEOLOGY

The white clay deposits in the vicinity of Mount Holly Springs occur in phyllite beds of the Tomstown Formation. This formation is

TABLE 3.—*Chemical and mineralogical composition of residual clayey silt from the pit near Dillsburg, York County*

| Description | Depth (meters) | Moisture (percent) | Chemical analyses[1] (percent) | | | | | | | | Grain-size distribution (percent) | | | Clay minerals[2] (ratio) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | SiO$_2$ | Al$_2$O$_3$ | Fe$_2$O$_3$ | CaO | K$_2$O | TiO$_2$ | Loss on ignition 1,000°C | Sum | Sand | Silt | Clay | Kaolinite | Illite | Goethite |
| North face of pit: | | | | | | | | | | | | | | | | |
| Clayey silt (5Y9/2)[3] | 1.0 | 10.3 | 72 | 18 | 0.6 | 0.3 | 2.1 | 1.0 | 5.8 | 99.8 | 6 | 52 | 42 | 9 | 1 | -- |
| Silty clay (10YR8/1) | 3.0 | 14.4 | 66 | 20 | .8 | .3 | 3.6 | 1.1 | 6.0 | 97.8 | 2 | 35 | 63 | 7 | 3 | -- |
| Silty clay (2.5Y8/4) | 4.5 | 13.9 | 70 | 17 | 2.3 | .2 | 3.3 | .9 | 4.5 | 98.2 | 8 | 36 | 56 | 6.5 | 3.5 | -- |
| Auger hole: | | | | | | | | | | | | | | | | |
| Clayey silt (10YR7/6) | 1.0 | 16.7 | 62 | 13 | 15.0 | .1 | 2.8 | .8 | 5.7 | 99.4 | 10 | 58 | 32 | 4 | 1 | 5 |
| Clayey silt (10YR8/1) | 2.0 | 14.6 | 71 | 16 | .9 | .2 | 3.9 | .8 | 4.3 | 97.1 | 7 | 62 | 31 | 6.5 | 3.5 | -- |
| Clayey silt (10YR7/6) | 3.0 | 15.8 | 60 | 14 | 13 | .4 | 4.1 | .8 | 6.0 | 98.3 | 5 | 50 | 45 | 3 | 3 | 4 |
| Clayey silt (10YR7/4) | 4.5 | 13.6 | 71 | 15 | 3.8 | .4 | 2.3 | .7 | 4.5 | 97.7 | 16 | 57 | 27 | 8 | 1 | 1 |
| Do | 6.0 | 15.4 | 71.3 | 15.7 | 3.6 | 1.7 | 1.9 | .7 | 5.1 | 100.0 | 16 | 49 | 35 | 8 | 1 | 1 |
| Clayey silt (10YR6/4) | 9.0 | 15.6 | 59 | 15 | 12 | .4 | 2.8 | .9 | 5.7 | 95.8 | 17 | 45 | 38 | 6 | 1 | 3 |
| Do | 12.0 | 16.6 | 51 | 11 | 24 | .4 | 3.0 | .7 | 6.0 | 96.1 | 14 | 43 | 43 | 4.5 | 1.5 | 4 |
| Clayey silt (10YR6/6) | 15.0 | 17.2 | 58 | 14 | 13 | .4 | 3.5 | .8 | 5.9 | 95.6 | 7 | 51 | 42 | 5.5 | 1.5 | 3 |

[1] Chemical analyses by X-ray fluorescence methods.
[2] Based on X-ray diffraction peak-area ratios; 7.1 A basal peak for kaolinite and 10.0 A basal peak for illite.
[3] Color designations are based on the "Munsell Soil Color Chart" (Munsell Color Co., 1954).

composed of thick-bedded, dense, bluish-gray dolomite, light-gray thin-bedded limestone, and light-gray phyllite. The dolomite weathers to a tough reddish-brown residuum composed of kaolinite and illite; the limestone weathers to a sticky yellow clay consisting of illite and kaolinite; and the phyllite weathers to a variegated silty clay containing predominantly kaolinite and some illite.

The Mount Holly Springs area has been intensely folded and faulted. According to Stose (1953), South Mountain is an anticline composed of the Montalto Quartzite Member of the Harpers Schist in the core and Antietam Quartzite on the flanks; Piney Mountain is homoclinal and is composed of the Weverton Quartzite, Montalto Quartzite Member, and the Antietam Quartzite; the longitudinal valley of Mountain Creek is synclinal and underlain by the Tomstown Formation. Freedman (1967) made two major changes in Stose's geologic map in the area of the clay deposits. He believed that the quartzite underlying South Mountain is the Montalto Quartzite Member instead of Antietam Quartzite and that a major fault is along the southeast-facing slope of South Mountain. The author agrees with Freedman's interpretation on the basis of the exposure made available by open-pit mining and the data obtained from two auger holes. The fault is steeply dipping to the southeast and has a relative upward movement on the northwest side. The phyllite beds of the Tomstown exposed in the Toland pit are tightly folded and contorted.

All the clay deposits in the Mount Holly Springs area and the clay deposit near Dillsburg undoubtedly were formed in the same geologic environment. All deposits are in the phyllite beds of the Tomstown and are located near the fault contact with the Montalto Quartzite Member. This fault is probably the principal reason for the formation of these deposits.

The white clay deposit at Toland is lens shaped, measuring approximately 60 m at its maximum width and 500 m in length (fig. 3); its vertical extent is probably about 90 m. The northern boundary of the deposit, where it is in fault contact with the quartzite of the Montalto Member, is sharp and straight. The southern boundary is gradational; the white clay grades into yellow, pink, red, and brown silty clay. This varicolored silty clay, which is about 60 m wide, grades into grayish-green to light-gray phyllite and calcite-veined limy phyllite of the Tomstown Formation.

Two auger holes were drilled in the floor of the pit (fig. 3). Auger hole 2 penetrated white clay for its entire depth of 46 m. Auger hole 1 penetrated white clay to a depth of 24 m, and then variegated silty clay (table 4). The projection of the variegated silty clay-white clay contact at the surface with its position at a depth of 24 m in auger hole 1 indicates an approximate dip of 60° N. If dip of this contact does not
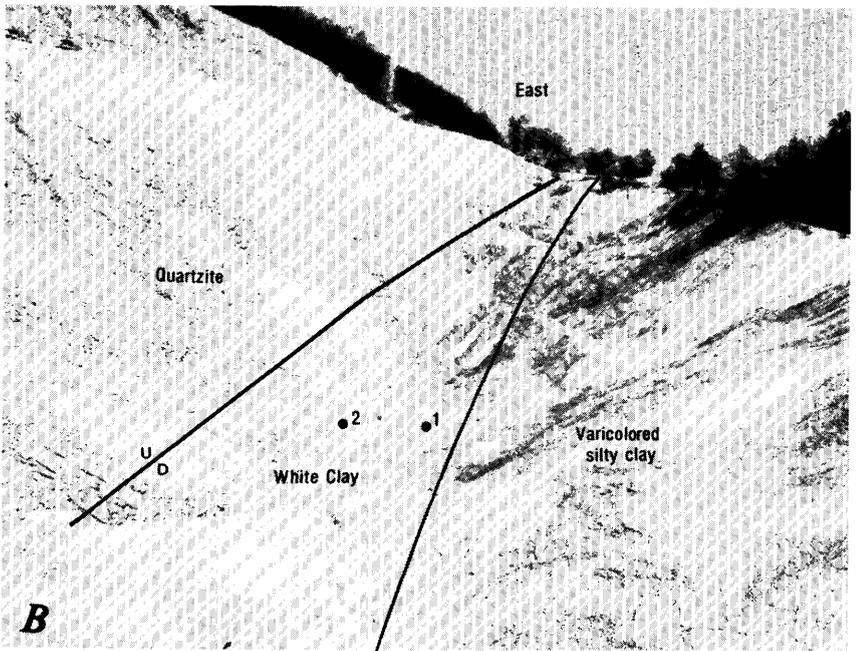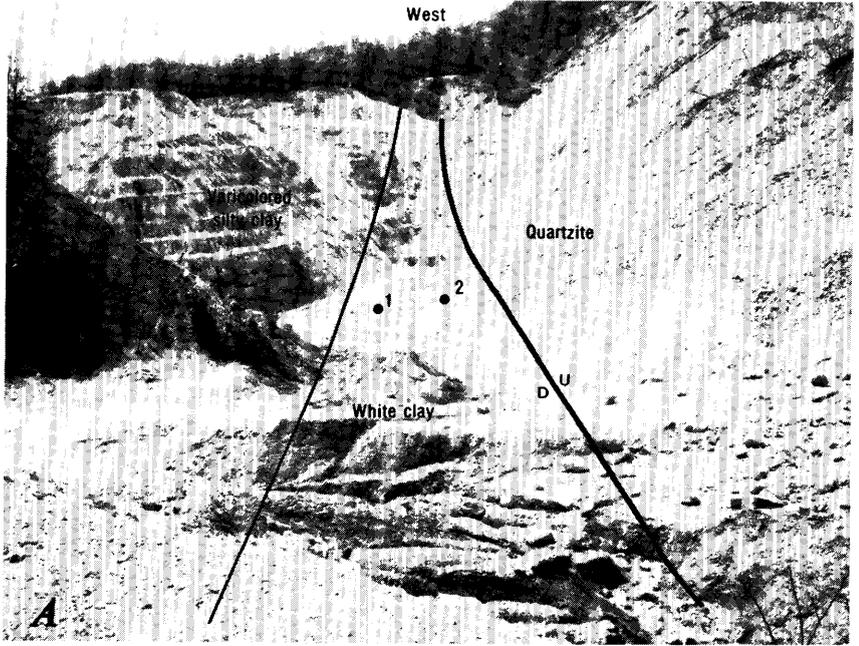
change at increased depth, the deposit wedges out against the steeply dipping fault at about 90 m below the present level of the pit floor. Bedding in the white clay is not distinguishable because open-pit mining has exposed only clay that has been disturbed by previous underground mining. Adjacent to the white clay, the sandy beds in the variegated silty clay, although very contorted, have an average dip of 60° N. The similarity between the dip of the beds and the dip of the contact near the haulageway indicates that there may be some bedding control to the alteration (p. D34), even though the contact does cross the bedding toward the east and west ends of the pit.

## COMPOSITION

The white clay, the varicolored silty clay, and the weathered phyllite in the Philadelphia Clay Co. pit at Toland show progressive differences in particle-size content, clay-mineral ratio, and $SiO_2$ and $Fe_2O_3$ content (table 5). As depth increases, the white clay decreases in sand and silt and increases slightly in clay. The sand and silt in the white clay are composed chiefly of quartz and trace amounts of muscovite. The sand and silt in the variegated color silty clay are composed of fine-grained quartz and some hematite and limonite. The sand and silt in the slightly weathered phyllite are composed of fine-grained quartz and small amounts of muscovite, biotite, and magnetite. Some of the phyllite contains limy beds and calcite veins.

The $SiO_2$ content of the rocks at the surface decreases from the white clay through the variegated silty clay to the weathered phyllite, whereas both the $Fe_2O_3$ and $K_2O$ contents increase. The $Al_2O_3$ content varies only a few percent without any discernible trend except for a slight decrease from the variegated silty clay into the weathered phyllite. The $TiO_2$ content remains constant (Hosterman, 1969b, fig. 3). In addition to these chemical variations, the following mineralogical changes take place: kaolinite is most abundant in the white clay and least abundant in the phyllite; illite is least abundant in the white clay and most abundant in the phyllite. The differences in chemical and mineralogical composition may be due to weathering, but they may also be due to differences in the lithology. The $Al_2O_3$ content does not change very much as a result of either weathering or clay mineralogy. An explanation for this is that the $Al_2O_3$ content in

◀FIGURE 3.—Clay pit of the Philadelphia Clay Co. at Toland showing location of auger holes. *A.* View looking west shows Montalto Quartzite Member of the Harpers Schist on right (north), white clay in center, and varicolored silty clay on left (south). *B.* View looking east shows Montalto Quartzite Member on left (north) being stripped, white clay in center, and varicolored clay on right (south). (Heavy line indicates fault contact; U, up; D, down.)

TABLE 4.—*Chemical and mineralogical composition of white clay from two auger holes drilled at the Toland clay pit near Mount Holly Springs, Cumberland County*

| Description | Depth (meters) | Moisture (percent) | Chemical analyses[1] (percent) | | | | | | | | Grain-size distribution (percent) | | | Clay minerals[2] (ratio) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | $K_2O$ | $TiO_2$ | Loss on ignition 1,000°C | Sum | Sand | Silt | Clay | Kaolinite | Illite |
| **Auger hole 1** | | | | | | | | | | | | | | | |
| Silty sandy clay (N9)[3] | 0.0 | 12.8 | 86 | 8 | 0.1 | 0.1 | 1.3 | 0.4 | 2.9 | 98.8 | 20 | 38 | 42 | 7.5 | 2.5 |
| Silty sandy clay (N9) | 3.0 | 16.7 | 78 | 16 | .2 | .1 | 1.1 | .7 | 2.9 | 99.0 | 20 | 19 | 61 | 9 | 1 |
| Silty clay (N9) | 6.0 | 19.7 | 75 | 17 | .3 | .2 | 1.4 | .8 | 5.6 | 100.3 | 7 | 25 | 68 | 9 | 1 |
| Do | 9.0 | 16.3 | 70 | 20 | .4 | .2 | 1.3 | .9 | 6.9 | 99.7 | 17 | 22 | 61 | 9 | 1 |
| Do | 12.0 | 20.4 | 70 | 20 | .2 | .2 | 1.7 | 1.0 | 6.4 | 99.5 | 7 | 23 | 70 | 9 | 1 |
| Do | 15.0 | 21.3 | 70 | 20 | .2 | .2 | 1.3 | .9 | 6.1 | 98.7 | 6 | 24 | 70 | 9 | 1 |
| Silty clay (10YR9/1) | 18.0 | 22.6 | 68 | 20 | .6 | .2 | 2.0 | 1.1 | 7.2 | 99.1 | 4 | 26 | 70 | 9 | |
| Silty clay (10YR10/1) | 21.0 | 21.7 | 67 | 20 | .6 | .3 | 2.1 | 1.1 | 7.6 | 98.7 | 2 | 22 | 76 | 8.5 | 1.5 |
| Silty clay (10YR9/1) | 24.5 | 21.5 | 69 | 20 | .5 | .2 | 2.2 | 1.0 | 6.4 | 99.3 | 5 | 22 | 68 | 8.5 | 1.5 |
| Silty clay (5YR8/2) | 27.5 | 24.8 | 68 | 18 | 1.2 | .4 | 3.1 | 1.0 | 6.4 | 98.1 | 8 | 20 | 72 | 8.5 | 1.5 |
| Silty clay (10YR7/2) | 30.5 | 23.9 | 70 | 14 | 1.8 | .3 | 2.6 | .9 | 8.3 | 97.9 | 11 | 17 | 72 | 8.5 | 1.5 |
| **Auger hole 2** | | | | | | | | | | | | | | | |
| Sandy clay (N9) | 0.0 | 19.9 | 80 | 14 | 0.2 | 0.3 | 0.7 | 0.6 | 3.9 | 99.7 | 30 | 20 | 50 | 9.5 | 0.5 |
| Silty clay (N9) | 3.0 | 18.4 | 72 | 19 | .4 | .3 | 1.2 | .9 | 5.7 | 99.5 | 12 | 25 | 63 | 9.5 | .5 |
| Do | 6.0 | 26.6 | 73 | 18 | .4 | .3 | 1.6 | .9 | 5.6 | 99.8 | 3 | 26 | 71 | 9.5 | .5 |
| Do | 9.0 | 26.5 | 70 | 19 | .4 | .2 | 1.4 | 1.0 | 6.9 | 98.9 | 4 | 23 | 73 | 9.5 | .5 |
| Do | 12.0 | 23.8 | 71 | 20 | .4 | .4 | 1.1 | 1.0 | 5.5 | 99.4 | 6 | 24 | 70 | 9.5 | .5 |
| Do | 15.0 | 22.5 | 70 | 21 | .3 | .2 | 1.2 | 1.0 | 5.9 | 99.6 | 8 | 22 | 70 | 9.5 | .5 |
| Do | 18.0 | 24.2 | 69 | 20 | .4 | .2 | 1.4 | 1.0 | 7.9 | 99.9 | 6 | 21 | 73 | 9.5 | .5 |
| Do | 21.0 | 22.1 | 73 | 19 | .4 | .2 | 1.3 | .9 | 5.6 | 100.4 | 5 | 25 | 70 | 9.5 | .5 |
| Do | 24.5 | 22.1 | 72 | 19 | .4 | .3 | 1.2 | .9 | 5.9 | 99.7 | 5 | 25 | 70 | 9.5 | .5 |
| Do | 27.5 | 25.3 | 71 | 21 | .4 | .3 | 1.0 | 1.1 | 6.2 | 101.0 | 5 | 23 | 72 | 9.5 | .5 |
| Do | 30.5 | 24.7 | 68 | 23 | .5 | .2 | 1.0 | 1.1 | 6.6 | 100.4 | 2 | 26 | 72 | 9.5 | .5 |
| Do | 33.5 | 24.9 | 68 | 23 | .4 | .1 | 1.3 | 1.1 | 6.2 | 100.1 | 5 | 24 | 71 | 9.5 | .5 |
| Clay (N9) | 36.5 | 28.3 | 68 | 23 | .5 | .3 | 1.1 | 1.1 | 5.8 | 99.8 | 2 | 18 | 80 | 9.5 | .5 |
| Clay (10R8/1) | 39.5 | 23.4 | 67 | 24 | .7 | .3 | 1.1 | 1.2 | 6.2 | 100.5 | 5 | 20 | 75 | 9.5 | .5 |
| Clay (N9) | 42.5 | 24.9 | 64 | 25 | .4 | .3 | 2.0 | 1.2 | 6.2 | 99.1 | 5 | 20 | 75 | 9 | 1 |
| Silty clay (N9) | 45.5 | 23.9 | 63 | 25 | .5 | — | 2.4 | 1.2 | 7.5 | 99.6 | 5 | 25 | 70 | 8.5 | 1.5 |

[1] Chemical analyses by X-ray fluorescence methods.

[2] Based on X-ray diffraction peak-area ratios; 7.1 A basal peak for kaolinite and 10.0 A basal peak for illite.

[3] Color designations are based on the "Munsell Soil Color Chart" (Munsell Color Co., 1954).

illites can be almost as high as it is in kaolinite. This is confirmed by the chemical analyses of some illites published by Grim (1953, p. 372).

TABLE 5.—*Average composition of clay and enclosed rocks at the Toland pit*

| | No. of samples | Sand | Silt | Clay | Clay minerals | | | SiO$_2$ | Al$_2$O$_3$ | Fe$_2$O$_3$ |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Kaolinite | Illite | Smectite | | | |
| | | (percent) | | | (ratio) | | | (percent) | | |
| White clay | 30 | 6 | 24 | 70 | 9 | 1 | — | 71 | 19 | 0.4 |
| Variegated silty clay | 3 | 5 | 34 | 61 | 8 | 2 | trace | 66 | 19 | 2.2 |
| Weathered phyllite | 5 | 7 | 33 | 60 | 1 | 7 | 2 | 56 | 18 | 6.3 |

The nature and attitude of the southern boundary of the white clay deposit are obtained from observations in the clay pit and from the chemical and mineralogical data from auger hole 1. The auger hole (table 4) was drilled approximately 18 m from the contact with the variegated silty clay. The high SiO$_2$ and low Al$_2$O$_3$ content of the first sample (table 4) is due to contamination from the quartzite and sand washed into the clay pit from the nearby spoil bank. The samples taken at 3 and 6 m are slightly higher in silt content that the average white clay at increased depth; therefore, the SiO$_2$ content is higher and the Al$_2$O$_3$ content is lower than the average-grade white clay. At a depth of 24 m, the hole penetrated variegated silty clay. At a depth of 24 m, the hole penetrated variegated silty clay. The boundary between the two clays is placed at a marked color change from white (N9) and yellowish white (10YR9/1) to light orange pink (5YR8/2 and 10YR7/2) (Munsell Color Co., 1954). At this boundary, the Fe$_2$O$_3$ content increases from 0.5 percent (yellowish white) to 1.2 percent (light orange pink). However, the fact that the SiO$_2$ content remains fairly constant indicates no increase in the amount of sand and silt present. In addition, illite increases and kaolinite decreases. The kaolinite-illite ratio above 18 m is 9:1 and below 18 m is 8:2 (table 4). Traces of alunite were observed in X-ray diffraction patterns in samples from between 9 and 24 m (Hosterman, 1969b, fig. 6).

The chemical and mineralogical data obtained from samples of auger hole 2 indicate that weathering or katamorphic alteration may have been the main geologic process, but evidence for hydrothermal alteration is also present. Auger hole 2 was drilled in white clay approximately 44 m from the contact with variegated silty clay. The high SiO$_2$ and low Al$_2$O$_3$ content (table 4) of the surface samples is possibly due to quartz contamination resulting from blasting and stripping of the Montalto Quartzite Member of the Harpers Schist on the mountain slope above the clay pit. From 6 to 45.5 m, the SiO$_2$ decreases from 73 to 63 percent, the Al$_2$O$_3$ increases from 18 to 25

percent, the $Fe_2O_3$ and $TiO_2$ are relatively constant, and the $K_2O$ is fairly constant down to 39.5 m but increases from 1.1 to 2.4 percent below 39.5 m. The kaolinite-illite ratio is greater than 9:1, and the color, with one exception, is white (N9) in all 16 samples examined. Alunite occurs in trace amounts from 12 to 39.5 m and in slightly more than trace amounts from 39.5 to 45.5 m. The bulk lithology of the white clay is virtually the same from 6 to 45.5 m with very little variation in the sand-silt-clay ratios (table 4). Thus, the steady increase of $Al_2O_3$ as depth increases and the complementary decrease of $SiO_2$ cannot be attributed to differences in lithology. This increase in $Al_2O_3$ content as depth increases, however, is the reverse of the change normally observed in a weathering profile (Hosterman and others, 1960, p. 13), but indicates hydrothermal alteration.

Tests by Shaw (Leighton, 1934, p. 12) indicated that the clay from the Mount Holly Springs area has good plasticity, low green strength, and fires to a light-cream to light-gray color. Paper-grade tests of a representative sample from the Philadelphia Clay Co. pit indicated a brightness of 79.3 percent; viscosity, tested on samples containing 68 percent solids, is 700 and 656 centipoises at spindle speeds of 10 and 100 revolutions per minute, respectively. White clay from this deposit tested the highest in paper-grade quality of all white clays in Pennsylvania.

## CLAY DEPOSITS IN THE GATESBURG FORMATION OF CENTRE, BLAIR, HUNTINGDON, AND BEDFORD COUNTIES

### LOCATION AND HISTORY

All the clay deposits discussed in this section are in the Gatesburg Formation of Late Cambrian age. The three largest and most recently mined clay pits in the Gatesburg are in Stormstown, Centre County, operated by the Harbison-Walker Refractories Co.; Oreminea 1, Blair County, owned by the Woodbury Clay Co.; and Oreminea 2, Blair County, operated by Grannas Brothers, Inc. Other older and much smaller clay pits in the Gatesburg are in Baileyville and Kelsey, Centre County; Dungarvin, Pennington, and Shoenberger, Huntingdon County; Martinsburg, Blair County; and Ore Hill and Bakers Summit, Bedford County (fig. 4).

The historical records on production of clay from the Gatesburg Formation in central Pennsylvania are very sketchy. White clay was

probably first found in the middle to late 19th century when there was considerable prospecting for iron ore. During World War I, the amount of imported white clay from Europe was greatly reduced. This stimulated the mining of white clay in this area (Moore, 1922) that lasted until about 1935. World War II caused a renewal in the production of white clay for the refractory industry, which then remained fairly steady for about 20 years. Since 1963, the amount of clay produced by the industry from central Pennsylvania has decreased steadily; at present only a very small amount is mined each year.
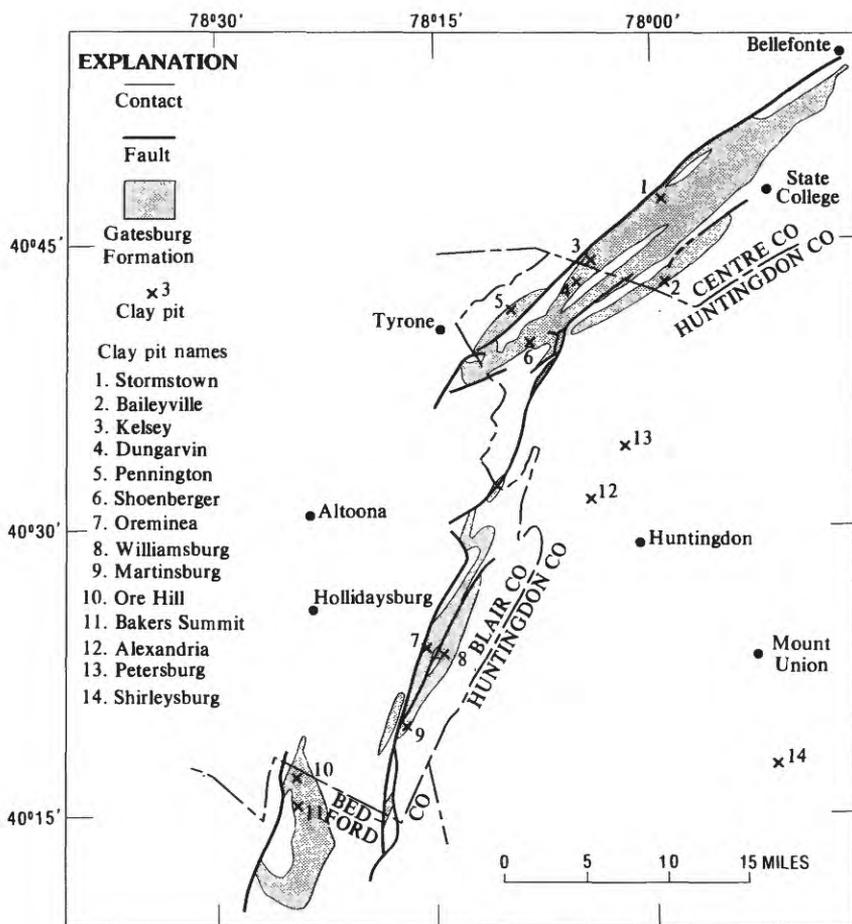


FIGURE 4.—Outcrop belt of the Gatesburg Formation (shaded areas) containing clay deposits and clay pits (X) in the Oriskany Group in Centre, Blair, Hunting don, and Bedford Counties, Pa., modified from Gray and others (1960).

## GEOLOGY

The clay deposits in the Gatesburg Formation are within a more or less homogeneous assemblage of Upper Cambrian silty dolomites. According to Butts and others (1939, p. 10), the Gatesburg is about 533 m thick and is composed predominantly of thick-bedded, coarsely crystalline, medium-gray dolomite with a small amount of thin-bedded, fine-grained medium-gray dolomite and a few beds of sandstone generally cemented with dolomite or calcite. The best exposure of unweathered Gatesburg is southeast of Tyrone on the Blair-Huntingdon County line (fig. 4) where Pennsylvania Highway 350 cuts through the dolomite along the Little Juniata River 0.8 km southeast of Birmingham. Six samples of rock were taken at random from exposures in a roadcut that is 370 m long. One sample contains a small amount of calcite in the dolomite, and the others are all dolomite. The acid-insoluble residue from these rock samples averages approximately 25 percent of the whole rock and ranges from 9 to 40 percent. The grain size of the insoluble material is predominantly clay and silt with a trace of sand; however, half of the insoluble material from one sample is sand. The insoluble material is composed of illite, some chlorite, quartz mainly in the form of chert, feldspar (chiefly microcline), and magnetite.

All clay deposits in the Gatesburg Formation are undoubtedly products of similar geologic environments. The outcrop pattern of the Gatesburg (fig. 4) shows a series of fault contacts on the north and northwest sides of the belt, and several additional faults are known to cut the formation. Because exposures are scarce and poor, many more faults and fractures than are indicated on the map may exist in these rocks. The lack of bedding or sedimentary features is evident in the recently worked clay pits, such as Oreminea 1, Oreminea 2, and Stormstown. Faults and fractures, along with the lack of bedding, may be a major factor in the formation of the clay deposits.

The clay body in Oreminea 1, the largest of the elliptical types, is 300 m long, 150 m wide, and about 30 m deep. Stormstown (fig. 5), the largest of the lens types, is 75 m wide, more than 600 m long, and 6 m deep. This deposit is probably several hundred meters longer but is narrower to the west where the clay has not been removed. The deposit at Oreminea 2 is elliptical in shape measuring 90 by 200 m and 9 m deep. The size of the other clay deposits that could be measured are Baileyville, 90 by 200 m; Kelsey, 20 by 100 m; Dungarvin, 200 by 400 m; Shoenberger, 60 by 300 m; Martinsburg, 60 by 150 m; and Bakers Summit, about 60 by 60 m.

## COMPOSITION

At the Stormstown clay pit (fig. 5), 11 samples were taken from a 19-m auger hole and 23 samples were taken at 3-m intervals across the 75-m exposed face of the clay pit (table 6). The grain-size composition of the 34 samples which averaged 34 percent sand, 10 percent silt, and 56 percent clay, indicated that the deposit is a very sandy clay. The sand and silt fractions are composed of quartz, and the clay-size fraction is virtually pure kaolinite. No evidence of any mineralogical or chemical changes was found at greater depths (table 6); such changes might be expected if the deposit is the result of katamorphic alteration in situ. The only noticeable variation is from the samples taken across the face of the pit. Here, there is a very slight increase in the amount of iron at the north and south edges of the pit. The color of the clayey sand is predominantly white to yellowish white, and where the iron content increases (table 6), it is slightly pink or orange.

Physical tests published by Ries and others (1922, p. 95) stated that the clay at Stormstown (Blair property) has an absorption of 15.7 percent, hardness of steel, and a faint cream-white color when fired at 1,350°C. They also indicated that the clay would be suitable, after washing, for whiteware and pottery. The paper-grade tests of the Harbison-Walker Refractory Co. clay pit near Stormstown show a brightness of 72.8 percent. The viscosity, tested on samples containing 71 percent solids, is 270 and 130 centipoises at spindle speeds of 10 and 100 revolutions per minute, respectively. These tests indicate that the clay is not of paper-grade quality.

The clay in the Oreminea 1 pit has been mined out, and it was not possible to obtain a representative sample of the material produced in this area. However, samples of similar, though possibly of somewhat lower grade, clay were taken when five auger holes were drilled in the vicinity of the pit (fig. 6 and table 7). The average grain-size composition of the 38 samples from these five holes, which was 40 percent sand, 33 percent silt, and 27 percent clay, indicated that this material is a clayey silty sand. The sand and silt fractions are composed of quartz, and the clay-size fraction is mostly kaolinite and small amounts of illite. No evidence of mineralogical or chemical changes was found at greater depths (table 7); such changes might be expected if the deposit is a result of weathering in place. The paper-grade tests of representative samples from the five auger holes near the Oreminea 1 clay pit show a brightness of 72.7 percent. The viscosity, tested on samples containing 71 percent solids, is 80 and 85 centipoises spindle speeds of 70 and 100 revolutions per minute, respectively.
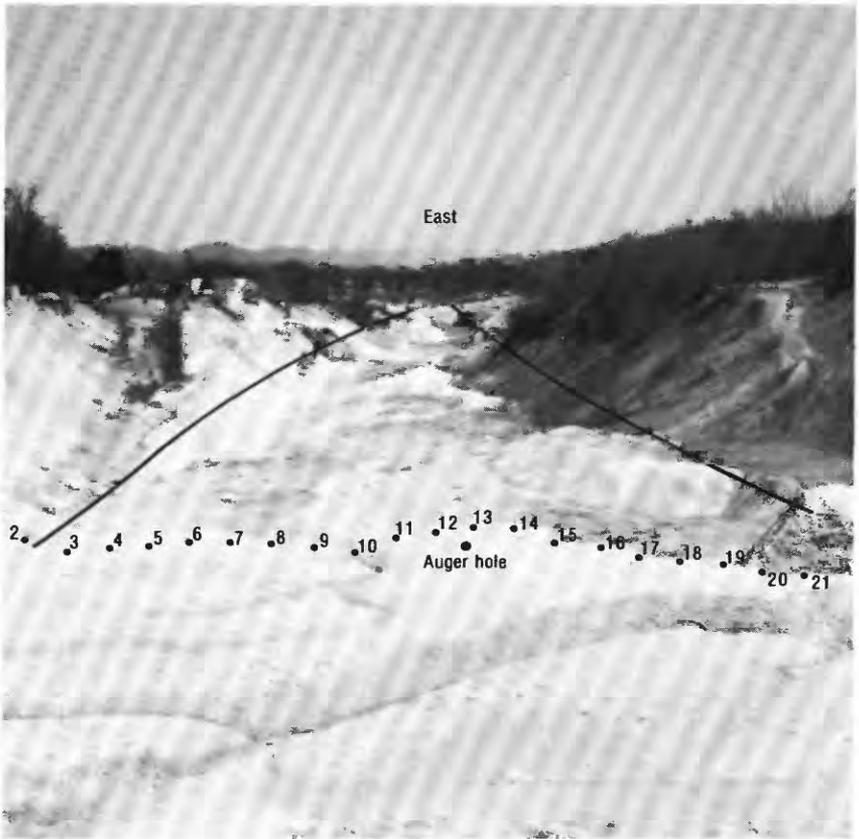
FIGURE 5.—Clay mine in the Stormstown pit, Centre County. The view is looking east and shows the north and south limits of the pit and the location of the auger hole. Numbers refer to sample locations.

At the Oreminea 2 clay pit, one auger hole was drilled to a depth of 9.5 m, and 10 samples were taken (table 7 and fig. 6). The average grain-size composition of this material, which is 17 percent sand, 35 percent silt, and 48 percent clay, indicates that it is a silty clay. The sand and silt fractions are composed of quartz, and the clay fraction is chiefly kaolinite and small amounts of illite. The paper-grade tests of representative samples from the Oreminea 2 clay pit showed a brightness of 75.8 percent. The viscosity, tested on samples containing 71 percent solids, is 2,710 and >1,000 centipoises with spindle speeds of 10 and 100 revolutions per minute, respectively.

Samples taken from five of the smaller older clay pits in the Gatesburg Formation were analyzed for mineralogical composition (table 8). In all samples, the sand and silt fractions are composed of

quartz. The clay fraction of a yellowish-gray, clayey sandy silt sample from the Baileyville pit contains kaolinite, illite, and smectite in approximately equal amounts. The high content of illite and smectite makes material from this pit undesirable for refractory products. The Dungarvin clay pit contains almost white, clayey silt that is composed of quartz and kaolinite and small amounts of illite. A sample from the Pennington pit proved to be a true clay, containing more than 80 percent clay-sized material. The clay is very pale orange and is composed of kaolinite and a trace of illite. The exposed material at the Shoenberger pit is yellowish-gray, silty clay composed chiefly of kaolinite and some illite. The pit near Martinsburg contains almost white, silty clay of which the clay fraction is 90 percent kaolinite and 10 percent illite.

## CLAY DEPOSITS IN THE ORISKANY GROUP
## OF HUNTINGDON COUNTY

In Huntingdon County, central Pennsylvania, the upper part of the Oriskany Group of Early Devonian age weathers to a white silty clay. The Oriskany Group can be divided into an upper unit of thick-bedded, coarse-grained sandstone (Ridgeley Sandstone) and a lower unit of chert and shale (Shriver Chert). Both units are typically cemented by calcite. The clay deposits are found in residual material derived from the lower chert and shale unit.

The refractory properties of these white clays were first recognized in 1870 when clay from the Alexandria pit was used to line local iron furnaces. During and after World War I, the white clay was used primarily by the steel mills as a mortar in laying refractory brick for coke ovens and open-hearth furnaces. Since World War II, the white clay has been used with flint clay in making refractory brick. In the past, these clay deposits were prospected and tested by paper and china-clay companies, but records do not indicate that the white clay was used either as a filler or in chinaware. The Alexandria Fire Clay Co. mined clay from the Shriver Chert at Alexandria, Huntingdon County, until the late 1970's. Other old clay pits in the Shriver Chert are found near Petersburg and Shirleysburg, Huntingdon County (fig. 4).

Samples from three of the clay pits were analyzed for their mineralogical composition (table 9). A representative sample from the Alexandria pit is a white clayey silt composed of quartz, illite, and some kaolinite. At the old Shirleysburg pit, the material is a light-gray silty clay composed of quartz and equal amounts of kaolinite and illite.

TABLE 6.—*Chemical and mineralogical composition of white clay from the Stormstown pit, Centre County*

| Description | Depth (meters) | Moisture (percent) | Chemical analyses[1] (percent) | | | | | | | | Grain-size distribution (percent) | | | Clay minerals[2] (ratio) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | $K_2O$ | $TiO_2$ | Loss on ignition 1,000°C | Sum | Sand | Silt | Clay | Kaolinite | Illite |
| West face of pit: | | | | | | | | | | | | | | | |
| Silty clay (10R8/3)[3] | | 17.0 | 61 | 27 | 0.7 | --- | 0.7 | 0.9 | 9.1 | 99.4 | 12 | 20 | 68 | 10 | 0 |
| Sandy clay (10YR9/2) | | 11.0 | 67 | 25 | .6 | --- | .5 | 1.0 | 5.9 | 100.0 | 28 | 9 | 63 | 10 | 0 |
| Sandy clay (2.5Y9/2) | | 12.0 | 72 | 19 | .3 | --- | .8 | 1.0 | 6.0 | 99.1 | 43 | 10 | 47 | 10 | 0 |
| Clayey sand (N9) | | 9.0 | 77 | 17 | .2 | --- | .5 | .8 | 4.3 | 99.8 | 49 | 8 | 43 | 10 | 0 |
| Do. | | 9.0 | 75 | 18 | .2 | --- | .6 | .7 | 4.8 | 99.3 | 48 | 8 | 44 | 10 | 0 |
| Clayey sand (2.5Y9/2) | | 9.0 | 75 | 18 | .3 | --- | .7 | .7 | 5.1 | 99.8 | 49 | 6 | 45 | 10 | 0 |
| Sandy clay (N9) | | 8.0 | 67 | 24 | .3 | --- | .6 | 1.0 | 6.9 | 99.8 | 29 | 10 | 61 | 10 | 0 |
| Do. | | 11.0 | 68 | 24 | .3 | --- | .4 | .9 | 6.6 | 100.2 | 29 | 11 | 60 | 10 | 0 |
| Clayey sand (N9) | | 9.0 | 76 | 17 | .2 | --- | .4 | .8 | 4.4 | 98.8 | 45 | 12 | 43 | 10 | 0 |
| Sandy clay (N9) | | 12.0 | 65 | 25 | .2 | --- | .2 | 1.0 | 7.5 | 99.1 | 25 | 12 | 63 | 10 | 0 |
| Clay (N9) | | 18.0 | 50 | 37 | .4 | --- | .4 | 1.2 | 11.1 | 99.9 | 6 | 4 | 90 | 10 | 0 |
| Sandy clay (N9) | | 14.0 | 64 | 26 | .2 | --- | .8 | 1.0 | 8.1 | 99.7 | 24 | 10 | 66 | 10 | 0 |
| Do. | | 12.0 | 69 | 22 | .3 | --- | .8 | 1.0 | 6.6 | 99.5 | 33 | 12 | 55 | 10 | 0 |
| Do. | | 12.0 | 68 | 23 | .3 | --- | .4 | .7 | 6.7 | 99.7 | 34 | 8 | 58 | 10 | 0 |
| Do. | | 10.0 | 67 | 23 | .2 | --- | .4 | .7 | 6.1 | 99.5 | 34 | 8 | 58 | 10 | 0 |
| Do. | | 13.0 | 66 | 24 | .3 | --- | .4 | .7 | 7.3 | 97.4 | 30 | 10 | 60 | 10 | 0 |
| Clayey sand (2.5Y9/2) | | 8.0 | 67 | 24 | .5 | --- | .4 | .7 | 6.2 | 98.7 | 32 | 8 | 60 | 10 | 0 |
| Sand (2.5Y9/4) | | 9.0 | 90 | 7 | .3 | --- | .5 | .2 | 1.9 | 98.8 | 76 | 6 | 18 | 10 | 0 |
| Sandy clay (N9) | | 9.0 | 71 | 22 | .2 | --- | .4 | .4 | 5.4 | 99.9 | 39 | 6 | 55 | 10 | 0 |
| Do. | | 9.0 | 68 | 23 | .1 | --- | .3 | .5 | 7.3 | 99.4 | 36 | 6 | 58 | 10 | 0 |
| Do. | | 10.0 | 68 | 24 | .1 | --- | .3 | .6 | 6.4 | 99.2 | 34 | 6 | 60 | 10 | 0 |
| Sandy clay (10YR8/3) | | 12.0 | 65 | 25 | .6 | --- | .3 | .5 | 7.2 | 99.4 | 30 | 7 | 63 | 10 | 0 |
| Do. | | 11.0 | 69 | 25 | .6 | --- | .2 | .5 | 4.6 | 98.6 | 33 | 7 | 60 | 10 | 0 |

North ◄———— 3-m interval ————► South

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Auger hole: | | | | | | | | | | | | | | | |
| Sandy clay (10YR9/1) ........ | 3.5 | 8.3 | 71 | 22 | .1 | .2 | .1 | 1.2 | 5.0 | 99.6 | 38 | 6 | 56 | 10 | 0 |
| Clay (10YR8/1) ........ | 4.5 | 10.6 | 57 | 30 | .2 | .3 | .3 | 1.7 | 11.0 | 100.5 | 7 | 18 | 75 | 10 | 0 |
| Sandy clay (N8) ........ | 6.0 | 9.6 | 61 | 28 | .4 | .2 | .3 | 1.8 | 7.3 | 99.0 | 18 | 12 | 70 | 10 | 0 |
| Sandy clay (10YR9/1) ........ | 7.5 | 10.6 | 63 | 26 | .2 | .0 | .1 | 1.0 | 9.5 | 99.8 | 26 | 9 | 65 | 10 | 0 |
| Do........ | 10.5 | 8.6 | 68 | 24 | .1 | .3 | .1 | 1.1 | 5.7 | 99.3 | 33 | 7 | 60 | 10 | 0 |
| Do........ | 12.0 | 10.3 | 74 | 19 | .2 | .2 | .1 | 1.0 | 5.2 | 99.7 | 43 | 9 | 48 | 10 | 0 |
| Do........ | 14.5 | 9.9 | 70 | 22 | .2 | .2 | .1 | 1.0 | 5.8 | 99.3 | 36 | 9 | 55 | 10 | 0 |
| Sandy clay (10YR8/2) ........ | 16.5 | 15.4 | 68 | 23 | .1 | .3 | .5 | 1.3 | 7.2 | 100.4 | 33 | 9 | 58 | 10 | 0 |
| Sandy clay (10YR9/2) ........ | 17.5 | 13.4 | 74 | 19 | .5 | .2 | .1 | 1.1 | 5.0 | 99.9 | 43 | 9 | 48 | 10 | 0 |
| Sandy clay (10YR9/1) ........ | 18.5 | 11.4 | 71 | 21 | .1 | .2 | .1 | 1.1 | 5.8 | 99.3 | 41 | 6 | 53 | 10 | 0 |
| Sandy clay (10YR8/1) ........ | 19.0 | 9.6 | 65 | 26 | .2 | .0 | .6 | 1.2 | 6.3 | 99.3 | 30 | 4 | 66 | 10 | 0 |

[1] Chemical analyses by X-ray fluorescence methods.

[2] Based on X-ray diffraction peak-area ratios: 7.1 A basal peak for kaolinite and 10.0 A basal peak for illite.

[3] Color designations are based on the "Munsell Soil Color Chart" (Munsell Color Co., 1954).

TABLE 7.—*Chemical and mineralogical composition of white silty clay from the Oremnea area, Blair County*

| Description | Depth (meters) | Moisture (percent) | Chemical analyses[1] (percent) | | | | | | | | Grain-size distribution (percent) | | | Clay minerals[2] (ratio) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | $K_2O$ | $TiO_2$ | Loss on ignition 1,000°C | Sum | Sand | Silt | Clay | Kaolinite | Illite |
| **Oreminea 1 clay pit** | | | | | | | | | | | | | | | |
| Auger hole 1: | | | | | | | | | | | | | | | |
| Silty clay (10YR7/1)[3] | 1.0 | 19.2 | 63 | 23 | 0.7 | 0.3 | 0.4 | 1.7 | 10.3 | 99.4 | 9 | 33 | 58 | 9.5 | 0.5 |
| Silty sand (10YR8/4) | 3.5 | 12.1 | 80 | 14 | .7 | .2 | .5 | .5 | 3.0 | 98.9 | 59 | 22 | 19 | 9 | 1 |
| Clayey silty sand (10YR8/2) | 4.5 | 16.6 | 74 | 18 | .5 | .2 | .6 | .8 | 5.2 | 99.3 | 35 | 35 | 30 | 9 | 1 |
| Clayey silty sand (10YR8/3) | 6.0 | 11.5 | 79 | 14 | .8 | .9 | .5 | .5 | 3.3 | 99.0 | 50 | 25 | 25 | 9 | 1 |
| Silty sand (10YR9/2) | 7.5 | 11.2 | 85 | 10 | .7 | .3 | .4 | .2 | 2.1 | 98.7 | 66 | 19 | 15 | 9 | 1 |
| Sandy silt (10YR8/1) | 9.0 | 13.8 | 89 | 6.9 | .2 | .3 | .6 | .2 | 1.8 | 99.0 | 43 | 45 | 12 | 8.5 | 1.5 |
| Clayey silty sand (10YR8/3) | 12.0 | 10.7 | 82 | 12 | 1.1 | .2 | .7 | .6 | 2.4 | 99.0 | 55 | 24 | 21 | 8.5 | 1.5 |
| Sand (10YR7/3) | 14.5 | 13.1 | 82 | 11 | 1.9 | .1 | 1.0 | .4 | 2.0 | 98.4 | 75 | 10 | 15 | 8 | 2 |
| Auger hole 2: | | | | | | | | | | | | | | | |
| Clayey sandy silt (N8) | 1.5 | 12.8 | 77 | 16 | .2 | .3 | .3 | .7 | 5.0 | 99.5 | 28 | 37 | 35 | 9.5 | .5 |
| Silty sand (N8) | 3.0 | 4.3 | 91 | 5.9 | .1 | .2 | .2 | .2 | 1.2 | 98.8 | 60 | 32 | 8 | 9.5 | .5 |
| Clayey sandy silt (N8) | 4.5 | 13.2 | 72 | 20 | .1 | .3 | .4 | .9 | 5.1 | 98.8 | 25 | 41 | 34 | 9.5 | .5 |
| Clayey silty sand (N8) | 6.0 | 11.0 | 82 | 13 | .1 | .3 | .3 | .5 | 3.1 | 99.3 | 49 | 30 | 21 | 9 | 1 |
| Silty sand (10YR8/1) | 7.0 | 5.0 | 90 | 6.6 | .2 | .3 | .3 | .2 | .8 | 98.4 | 74 | 16 | 10 | 9 | 1 |
| Silty sand (N8) | 9.0 | 4.4 | 91 | 5.6 | .2 | .3 | .3 | .3 | 1.1 | 98.7 | 70 | 16 | 14 | 8.5 | 1.5 |
| Clayey silty sand (10YR7/3) | 10.0 | 10.0 | 83 | 11 | 1.0 | .2 | .8 | .3 | 2.4 | 98.7 | 54 | 21 | 25 | 8.5 | 1.5 |
| Sandy silty clay (10YR7/1) | 12.0 | 15.2 | 71 | 19 | .6 | .3 | 1.5 | .7 | 5.9 | 99.0 | 22 | 39 | 39 | 8 | 2 |
| Clayey sand (10YR8/1) | 13.5 | 5.6 | 88 | 8.0 | .4 | .3 | .4 | .2 | 1.5 | 98.8 | 74 | 11 | 15 | 9 | 1 |
| Auger hole 3: | | | | | | | | | | | | | | | |
| Clayey sandy silt (10YR8/1) | 1.5 | 13.9 | 80 | 14 | .4 | .2 | .4 | .6 | 4.1 | 99.7 | 32 | 42 | 26 | 9.5 | .5 |
| Clayey silt (10YR8/1) | 3.0 | 15.5 | 74 | 18 | .2 | .2 | .5 | 1.0 | 5.5 | 99.4 | 11 | 57 | 32 | 9.5 | .5 |
| Clayey silt (N8) | 4.5 | 19.1 | 72.3 | 17.7 | .25 | .23 | .70 | .81 | 6.1 | 98.09 | 11 | 52 | 37 | 9.5 | .5 |
| Silty sandy clay (10YR8/1) | 5.5 | 19.2 | 82 | 12 | .3 | .2 | .4 | .5 | 3.8 | 99.2 | 27 | 36 | 37 | 9.5 | .5 |
| Clayey sandy silt (N8) | 6.0 | 15.2 | 83 | 11 | .1 | .3 | .4 | .4 | 4.4 | 99.6 | 25 | 48 | 27 | 9.5 | .5 |
| Clayey silty sand (N8) | 7.5 | 14.9 | 82 | 13 | .1 | .3 | 1.0 | .4 | 2.9 | 99.7 | 40 | 33 | 27 | 8.5 | 1.5 |
| Clayey sandy silt (N8) | 9.0 | 17.4 | 74 | 18 | .2 | .2 | 1.3 | .7 | 4.7 | 99.1 | 30 | 36 | 34 | 8.5 | 1.5 |
| Clayey sand (2.5Y9/2) | 13.0 | 10.8 | 90 | 7.3 | .2 | .2 | .6 | .2 | 1.4 | 99.9 | 73 | 13 | 14 | 8.5 | 1.5 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Auger hole 4:** | | | | | | | | | | | | | | |
| Silty clay (2.5Y8/2) | 1.0 | 15.7 | 70 | 20 | .4 | .1 | .7 | 1.1 | 7.8 | 100.1 | 13 | 42 | 45 | 9.5 | .5 |
| Clayey silt (10YR8/1) | 2.5 | 16.2 | 72.4 | 19.4 | .11 | .40 | .50 | .96 | 8.0 | 101.77 | 20 | 42 | 38 | 9.5 | .5 |
| Do | 4.0 | 18.0 | 70 | 19 | .2 | .2 | .7 | 1.1 | 8.1 | 99.3 | 6 | 57 | 37 | 9.5 | .5 |
| Silty clay (2.5Y8/2) | 5.5 | 18.6 | 63 | 25 | .3 | .4 | .6 | 1.3 | 8.8 | 99.4 | 10 | 37 | 53 | 9.5 | .5 |
| Clayey sandy silt (2.5Y8/2) | 6.5 | 14.9 | 75 | 17 | .4 | .3 | .5 | .8 | 5.4 | 99.4 | 26 | 39 | 35 | 9.5 | .5 |
| Silty silt (10YR8/1) | 7.5 | 17.8 | 70 | 20 | .3 | .3 | .8 | 1.0 | 7.8 | 100.2 | 17 | 50 | 33 | 9.5 | .5 |
| Clayey sandy silt (10YR7/4) | 8.0 | 14.8 | 69 | 18 | 3.2 | .2 | .6 | .9 | 7.8 | 99.7 | 31 | 39 | 30 | 9.5 | .5 |
| Clayey silty sand (7.5YR7/4) | 8.2 | 8.9 | 79 | 15 | .7 | .3 | .3 | .6 | 3.4 | 99.3 | 54 | 22 | 24 | 9.5 | .5 |
| Silty sand (7.5YR8/4) | 9.5 | 10.2 | 80 | 14 | .5 | .4 | .3 | .5 | 3.7 | 99.4 | 52 | 33 | 15 | 9.5 | .5 |
| | | | | | | | | | | | | | | |
| **Auger hole 5:** | | | | | | | | | | | | | | |
| Silty sandy clay (10YR8/2) | 2.0 | 12.0 | 79 | 14 | .4 | .4 | 1.5 | .6 | 4.0 | 99.9 | 34 | 27 | 39 | 7 | 3 |
| Clayey silty sand (10YR8/1) | 5.0 | 11.1 | 80 | 14 | .4 | .2 | .7 | .4 | 3.3 | 99.0 | 48 | 30 | 22 | 8.5 | 1.5 |
| Silty sand (2.5Y8/2) | 8.0 | 11.5 | 85 | 10 | .6 | .2 | .6 | .4 | 2.9 | 99.7 | 51 | 33 | 16 | 7.5 | 2.5 |
| Silty sand (10YR7/1) | 10.0 | 8.6 | 85 | 11 | .7 | .4 | .6 | .3 | 1.7 | 99.7 | 58 | 22 | 20 | 7.5 | 2.5 |

**Oreminea 2 clay pit**

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Auger hole 6:** | | | | | | | | | | | | | | |
| Silty clay (N8) | 1.8 | 11.5 | 65.1 | 24.1 | 0.11 | 0.0 | 0.25 | 1.5 | 8.9 | 99.96 | 4 | 35 | 61 | 10 | 0 |
| Silty sand (N9) | 2.0 | 1.8 | 82 | 14 | .2 | .2 | .2 | .4 | 3.0 | 100.0 | 73 | 8 | 19 | 9.5 | .5 |
| Silty clay (2.5Y7/2) | 4.0 | 17.9 | 65 | 22 | .7 | .2 | .6 | 1.2 | 9.6 | 99.3 | 5 | 37 | 58 | 9.5 | .5 |
| Silty clay (10YR8/1) | 5.0 | 13.7 | 67 | 23 | .3 | .2 | .6 | 1.2 | 7.0 | 99.3 | 14 | 35 | 51 | 9.5 | .5 |
| Do | 6.0 | 14.2 | 66 | 23 | .4 | .2 | .6 | 1.2 | 7.8 | 99.2 | 6 | 46 | 48 | 9.5 | .5 |
| Do | 6.5 | 13.6 | 67 | 23 | .3 | .4 | .5 | 1.3 | 7.6 | 100.1 | 5 | 45 | 50 | 9.5 | .5 |
| Clayey silt (10YR8/1) | 7.5 | 14.8 | 73.3 | 16.3 | .25 | .80 | .50 | 1.2 | 7.4 | 99.75 | 6 | 53 | 41 | 9.5 | .5 |
| Silty clay (10YR8/1) | 8.0 | 14.6 | 65 | 24 | .3 | .3 | .6 | 1.4 | 7.3 | 98.9 | 4 | 41 | 55 | 9.5 | .5 |
| Do | 9.0 | 15.6 | 66 | 23 | .2 | .1 | .6 | 1.3 | 7.6 | 98.8 | 15 | 33 | 52 | 9.5 | .5 |
| Sandy clay (N8) | 9.5 | 13.7 | 69 | 22 | .1 | .1 | .5 | 1.1 | 6.3 | 99.1 | 37 | 18 | 45 | 9.5 | .5 |

[1] Chemical analyses by X-ray fluorescence methods.

[2] Based on X-ray diffraction peak-area ratios; 7.1 A basal peak for kaolinite and 10.0 A basal peak for illite.

[3] Color designations are based on the "Munsell Soil Color Chart" (Munsell Color Co., 1954).

Near Frankstown, Blair County, at the General Refractories Co. sand quarry, the Ridgeley Sandstone is overlain by a 3.5 m bed of silty clay. This residual clay is probably derived from greenish-gray shale of the Onondaga Formation. The pale red silty clay is composed of quartz and equal amounts of kaolinite and illite (table 9).

TABLE 8.—*Mineralogical composition of clay from five small clay pits in the Gatesburg Formation, Centre, Huntingdon, and Blair Counties*

| Clay pit | Description | Grain-size distribution (percent) | | | Clay minerals[1] (ratio) | | |
|---|---|---|---|---|---|---|---|
| | | Sand | Silt | Clay | Kaolinite | Illite | Smectite |
| Baileyville ........... | Clayey sandy silt (10YR8/1)[2] ...... | 27 | 37 | 36 | 4 | 2 | 4 |
| Dungarvin ............ | Clayey silt (N9) .... ................ | 17 | 48 | 35 | 9 | 1 | -- |
| Pennington............ | Clay (10YR8/3)............................... | 4 | 15 | 81 | 9.5 | .5 | -- |
| Shoenberger ....... | Silty clay (10YR8/1) ..................... | 3 | 46 | 51 | 9 | 1 | -- |
| Martinsburg ....... | Silty clay (N9)............................... | 5 | 42 | 53 | 9 | 1 | -- |

[1] Based on X-ray diffraction peak area ratios.
[2] Color designations are based on the "Munsell Color Chart" (Munsell Color Co., 1954).

TABLE 9.—*Mineralogical composition of clay from three small pits in the Oriskany Group, Huntingdon County*

| Clay pit | Description | Grain-size distribution (percent) | | | Clay minerals[1] (ratio) | | |
|---|---|---|---|---|---|---|---|
| | | Sand | Silt | Clay | Kaolinite | Illite | Smectite |
| Alexandria.............. | Clayey silt (N9)[2] ............... | 11 | 49 | 40 | 2 | 8 | -- |
| Shirleysburg .......... | Silty clay (N7)..................... | tr | 35 | 65 | 5 | 5 | -- |
| Frankstown ........... | Silty clay (5R5/2)............... | 14 | 42 | 44 | 5 | 5 | -- |

[1] Based on X-ray diffraction peak area ratios.
[2] Color designations are based on the "Munsell Color Chart" (Munsell Color Co., 1954).

## ORIGIN OF THE WHITE CLAY DEPOSITS

The white clay deposits in Pennsylvania were formed by one or more geologic processes. Some of the clay deposits have been formed by katamorphic alteration, at least one clay deposit has been, in part, hydrothermally altered, and several clay deposits accumulated by sedimentary processes.

The deposits near Kunkletown and Saylorsburg, Monroe County, were formed by katamorphic alteration. The geological, mineralogical, and chemical data indicate that the clay deposits were derived from cherty, limy shales and argillaceous limestones. This alteration is the result of leaching by downward-percolating meteoric water in the New Scotland Formation, Shriver Chert, and Buttermilk Falls

Limestone. The following changes were observed: (1) calcite and dolomite are completely removed by chemical weathering; (2) chlorite, present in the fresh rock, is not found in the weathered rock; (3) illite occurs in approximately equal amounts in both the fresh and weathered rocks, but its crystalline state changes from $2M$ polymorph in the fresh rock to $Md$ polymorph in the weathered rock; and (4) kaolinte is found only in the weathered rock, and it probably is a



EXPLANATION

| €gm | |
|---|---|
| €g | |

Gatesburg Formation
€gm, Mines Dolomite Member

Contact
(approximately located)

Fault

Clay pit

Iron Ore Pit

Auger Hole

N
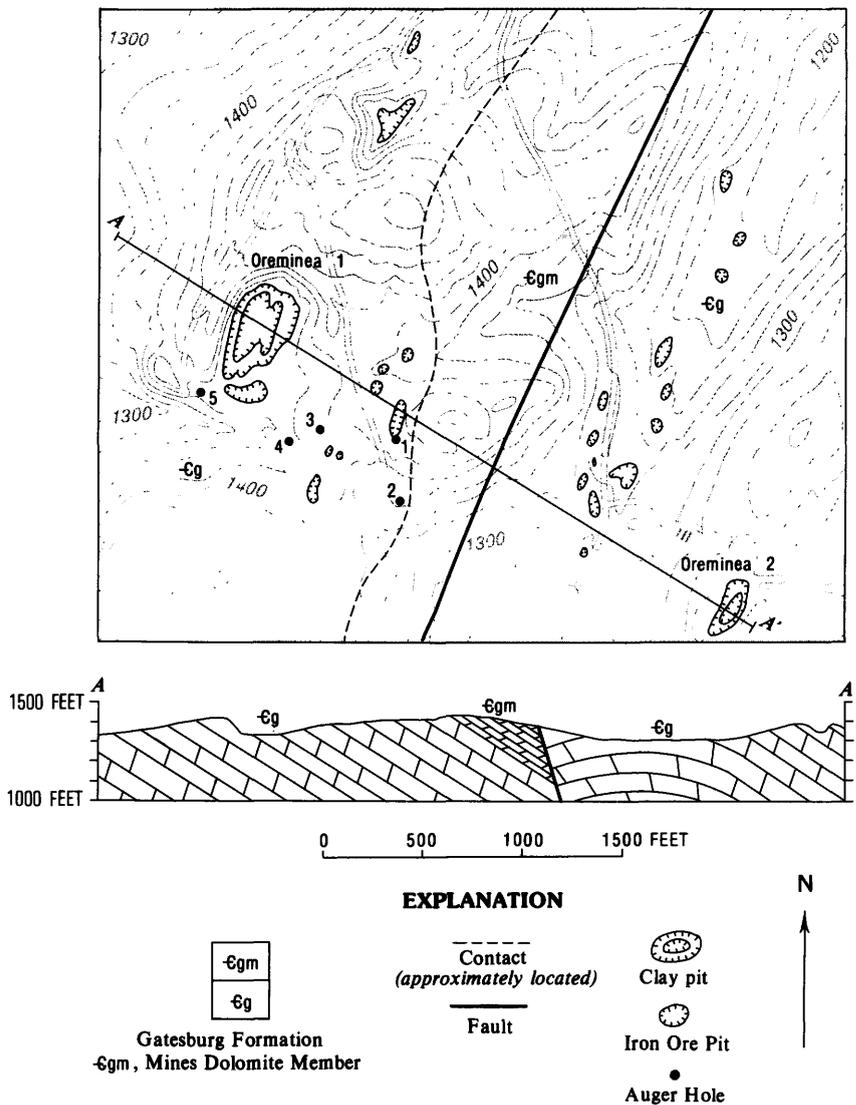
FIGURE 6.—Location of auger holes near the Oreminea 1 and Oreminea 2 clay pits. From Gray and others, 1960.

product of chlorite. The volume loss of 40 to 70 percent is a result of leaching the carbonates. The little or no difference in the amount of quartz or chert found in the fresh and in the weathered rocks indicates some loss in this mineral during leaching and with the volume change. The generally well preserved tectonic and sedimentary features in the pit face prove that the white silty clay is a sedimentary rock saprolite.

Narvon pit, Lancaster County, contains clayey silt derived from thin-bedded siltstone and argillite beds of the upper part of the Chickies Quartzite. The well-preserved sedimentary features in the pit face indicate that the deposit is also a sedimentary rock saprolite resulting from katamorphic alteration.

The clay deposits in the vicinity of Mount Holly Springs, Cumberland County, including the deposit near Dillsburg, York County, could have formed by katamorphic alteration, hydrothermal alteration, or both. Stose (1907, p. 323) proposed that the origin of the deposit was by weathering. However, the chemical and mineralogical data suggest that these clay deposits were formed, at least in part, by hydrothermal alteration (Hosterman, 1969b, p. B72). Although a likely source for hydrothermal activity has not been recognized, water heated at considerable depth may have moved upward along the faults associated with the clay deposits.

The chemical analyses, particularly the $Al_2O_3$ content of samples from auger hole 2 (table 4) supports the evidence of hydrothermal origin and does not support the theory that the white clay was formed exclusively as a residuum resulting from katamorphic alteration. In most weathering profiles the katamorphic alteraton shows that $SiO_2$, $Fe_2O_3$, and $K_2O$ are leached near the surface and increase in amount as depth increases and that the $Al_2O_3$ has its maximum amount at the surface and gradationally decreases toward the parent material. At the Philadelphia Clay Co. pit, the white clay could be considered to be the most weathered, the variegated silty clay the partially weathered, and the phyllite the unweathered parent material. $Fe_2O_3$ and $K_2O$ show a normal katamorphic alteration profile by increasing as depth increases, but hydrothermal alteration, at least in part, is indicated by $SiO_2$ decreasing and $Al_2O_3$ increasing as depth increases. The total sand and silt content remains constant below 20 feet; therefore, the decrease of $SiO_2$ cannot be due to a downward decrease in sand- or silt-size quartz. Also, as depth increases, the amount of clay does not increase to account for the downward increase in $Al_2O_3$ (table 4). Alunite accounts for part of the $Al_2O_3$ increase, but it occurs only in trace amounts. The additional $Al_2O_3$ content could be caused by a slight increase of aluminum in the kaolinite lattice and to the presence of allophane, which is amorphous to X-ray detection and almost

impossible to identify by differential thermal analysis in the presence of kaolinite. Kaolinite, the most abundant mineral present, can be formed either by hydrothermal alteration or by katamorphic alteration.

Semiquantitative spectrographic analyses by Joseph L. Harris, U.S. Geological Survey, of 16 samples from auger hole 2, also indicate the possibility of hydrothermal alteration. Three elements found associated with hydrothermal activity were found to be higher than average for most clays. The lead (Pb) averaged 50 parts per million (ppm) in auger hole 2 (table 4), and in most other clay material it is only about 10 ppm. The copper (Cu) content ranged from 20 to 150 ppm, slightly higher than in most other clays, which rarely have more than 50 ppm. The unique element was cerium (Ce), which averaged 200 ppm, and it is not detectable in most other clay materials. The chemical and mineralogical evidence indicates that the white clay deposits near Mount Holly Springs were probably formed by hydrothermal alteration. The surface features, the presence of supergene iron ore deposits, and the weathered phyllite all indicate that katamorphic alteration occurred after hydrothermal alteration.

The clay deposits found in the Gatesburg Formation of central Pennsylvania were formed by katamorphic alteration, erosion, and subsequent deposition. The chemical reaction of slightly acidic ground water leached the dolomite of the Gatesburg. Faults and fractures in the dolomite probably controlled the direction and course of the ground water creating caverns and sinkholes. Along with the removal of carbonate minerals, much of the insoluble material, which constitutes approximately 25 percent of the fresh rock, was chemically altered. The illite, chlorite, and feldspar from the parent rock are weathered to kaolinite with the removal of alkalies and iron. The iron from magnetite and chlorite was converted to soluble iron. Quartz remained unaltered. This chemically weathered material was eroded and deposited in previously formed sinkholes and caverns. Most of the clay deposits in the Gatesburg occur along the flanks of ridges or knolls of more resistant sandy material. The presence of a deposit is commonly indicated by a small depression in the land surface. The deposits are either elliptical or lens shaped. No bedding or sedimentary features have been observed in any of the pits. The grain-size distribution, (table 6 and 7) which shows a complete heterogeneity, indicates a lack of sorting. Also, none of the chemical or mineralogical data give evidence for katamorphic alteration in place, which suggests that the clay was transported and deposited in sinkholes and caverns of the Gatesburg Formation.

The clay deposits found in the Shriver Chert of central Pennsylvania have an origin similar to those deposits near Kunkletown and

Saylorsburg. They are products of katamorphic alteration, in place, of cherty limy shales. This alteration is the result of leaching by downward-percolating slightly acidic ground water.

The white clay deposits near Mount Holly Springs and Dillsburg and those in the Gatesburg Formation of central Pennsylvania are near iron pits that have been productive in the past. A close relationship exists between the white clay and iron oxide deposits. Surface waters that had a high oxygen content penetrated the fresh parent rock along fracture or fault planes and along bedding planes. The carbonate minerals were removed first by leaching, followed by the leaching of iron, potassium, and magnesium from illite, chlorite, and the accessory minerals. These elements were carried away in solution, and a residual deposit was left that was composed primarily of white kaolinitic silty clay. The iron, derived partly from illite, but chiefly from the magnetite in the unweathered Tomstown Formation or Gatesburg Formation, was probably precipitated from solution when the slightly acid ground water permeated the unleached carbonate beds of either the Tomstown or Gatesburg. Thus, the iron ore deposits in South Mountain mined during the mid- to late-19th century and the Scotio iron ore deposits mined during the late-19th and early-20th centuries, were formed by supergene enrichment and are similar in origin to those in Virginia (Lesure, 1957, p. 98).

It is difficult to determine the age of the white clay deposits in Pennsylvania. Undoubtedly the age of all the clay deposits is about the same because the climatic conditions conducive to katamorphic alteration were rather uniform throughout the entire region. The clay deposits near Kunkletown and Saylorsburg are southwest of a Wisconsin glacial terminal moraine. No clay deposits are known northeast of the moraine. Therefore, the clay deposits formed before the Wisconsin glaciation, and those northeast of the moraine were stripped away during glacial advance.

The interpretation by Pierce (1965) indicates that the Great Valley and Valley and Ridge provinces of Pennsylvania have been exposed to subaerial erosion and weathering since Cretaceous time, and possibly before. This establishes a possible age for the beginning of katamorphic alteration by weathering. Griffiths and others (1956) agreed that tropical weathering of central Pennsylvania during Cretaceous time is the most probable date for the beginning of the formation of the clay deposits. It is also reasonable to believe that the clay deposits are a product of prolonged weathering over several million years and that large amounts of unprotected residuum have been removed.

## CONCLUSIONS

The production of white clay in Pennsylvania has declined during the past 20 years. White clay is still being mined at Toland, Cumberland County, by the Philadelphia Clay Co. and near Kunkletown, Monroe County, by the Universal Atlas Co. Clay from these two deposits is being used to make white cement, and both deposits have many years of reserves at their current rate of production. Between Kunkletown and Saylorsburg, additional silty clay deposits are known on strike with the present pits. At Toland, additional clay is present at depth and also on strike with the present pit both east and west. The other clay deposits are not being mined currently because the demand for high-grade refractory clay brick has dropped. The known clay deposits in the Gatesburg Formation of central Pennsylvania do have some reserves, and there are probably a few undiscovered clay deposits, but, owing to current lack of demand, both mining and prospecting are at a standstill.

The idle clay pits may become sites for storing hazardous waste. Inert solid-waste material would not cause any problem to the environment, but liquid and chemical waste material would be hazardous because of the origin of the clay deposits. The clay deposits are composed of silty clay and clayey silt derived from katamorphic alteration of limestone or limy shales or phyllites. The alteration was the result of ground water percolating through the rock causing the formation of saprolite. Because the saprolite is very porous, any attempt to store liquid or chemical waste in it would contaminate the ground water and result in a hazard to the environment.

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