CLAYS AND SHALES OF PENNSYLVANIA

(Abstracts of Publications and Theses to 1970)

W. O. Williamson and F. L. Kennard

Special Report 1 - 71
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>ii</td>
</tr>
<tr>
<td>Publications of the United States Geological Survey</td>
<td>1</td>
</tr>
<tr>
<td>Publications of the United States Bureau of Mines</td>
<td>6</td>
</tr>
<tr>
<td>Publications of the Pennsylvania Geological Survey</td>
<td>7</td>
</tr>
<tr>
<td>Theses of The Pennsylvania State University</td>
<td>12</td>
</tr>
<tr>
<td>Publications of the College of Earth and Mineral Sciences (formerly College of Mineral Industries), The Pennsylvania State University</td>
<td>18</td>
</tr>
<tr>
<td>Papers Published in Various Journals</td>
<td>20</td>
</tr>
<tr>
<td>Miscellaneous Publications</td>
<td>24</td>
</tr>
</tbody>
</table>
Introduction

Information about the clays and shales of Pennsylvania, often with discussion of their present or potential ceramic uses, is scattered through official publications, the M.S. and Ph.D. theses of The Pennsylvania State University, and diverse technical and scientific journals. This information is here summarized as abstracts, which it is hoped will be useful to those interested in the clays and shales of the Commonwealth and particularly in their ceramic applications. It is unlikely that all the significant information has been located and abstracted and the senior editor (W.O.W.) will be grateful if his attention is directed to omissions, because it may be possible to publish supplementary abstracts in the future. However, some very old sources of information were deliberately omitted because they seemed to have little present value. Most of these can be found by consulting the bibliographies in the originals of certain of the documents here abstracted.

The Library of the College of Earth and Mineral Sciences, The Pennsylvania State University, has many of the abstracted documents available for consultation. Copies of these can usually be obtained from the Librarian on payment of a small fee. In a few instances, abstracted documents, unavailable in this Library, may be located in the Keramos-Prazier Collections of the Ceramic Science Section, Department of Material Sciences, of the above-mentioned College.

The sources of the abstracts were diverse and gave their information in various ways. Thus it was difficult to devise any scheme which would present, in summary form, the information which might happen to interest any particular inquirer. The abstracts have therefore been arranged under headings which denote the types of published or unpublished documents in which the information originally appeared. Under each heading, the abstracts follow the alphabetical order of the names of the authors of the source material or, if there is multiple authorship, that of the names which appear first in the sequence of co-authors.

Material in University theses frequently appears more briefly in scientific or technical journals with the thesis adviser cited as co-author. Thus there is some overlap between the abstracts of theses and those of journals. However, thesis material is sometimes modified or added to before publication in a journal.

One of us (F.L.K.) is grateful to Small Industries Research for the support which permitted him to assist in this project.
Publications of the United States Geological Survey

Ashley, G. H.


In a general description of the geology and distribution of clays and shales in southern Clearfield County, southeastern Jefferson County and northeastern Indiana County, Pennsylvania, flint clays, soft clays and shales are discussed separately.

Bascom, F. and G. W. Stose

"Description of the Coatesville and West Chester Quadrangles," U.S. Geol. Surv. Folio No. 225 (1932)

A survey was made of the geology and mineral resources of the Coatesville and West Chester Quadrangles. These quadrangles are located just west of Philadelphia, Pennsylvania. Included in the survey were the kaolins of this area. The locations, properties, and uses of known deposits are discussed.

Bascom, F. and G. W. Stose


These quadrangles consist of portions of Chester, Berks, Lancaster and Montgomery Counties. A survey of the known clay and shale resources was included in this investigation. The locations, physical properties, and uses of these deposits are discussed.

Butts, C.

"Description of the Rural Valley Quadrangle," U.S. Geol. Surv. Folio No. 125 (1905)

A survey was made of the geology and mineral resources of the Rural Valley Quadrangle in west-central Pennsylvania. Included in the survey of mineral resources were the clay deposits of this area. Known deposits of the Mercer, Clarion and Kittanning fire clays were investigated and locations, general properties and uses are given.
Butts, C.


A general survey was made of the geology of the mineral resources in the Kittanning and Rural Valley Quadrangles in west-central Pennsylvania. Both quadrangles lie mainly in Armstrong County with small sections in Butler and Clarion Counties. In the course of this survey, the clay and shale deposits were investigated. Properties, uses and mode of occurrence of various deposits of the Mercer, Clarion, Kittanning and Freeport fire clays are discussed and a number of chemical analyses tabulated.

Lines, E. F.


The clay and shale resources of the Clarion Quadrangle are discussed. Both materials are abundant within this quadrangle and many are suitable for commercial use. The geology and location of known beds of shales and of both flint and plastic clays are discussed separately as are some of the properties of these materials.

Some past and possible future uses are mentioned.

Phalen, W. C. and L. Martin


The clay and shale resources of southwestern Cambria County are discussed. The geology and location of known beds are considered and some of the properties of the clays are described. The materials mentioned are shales, flint clays, and plastic clays (including some fire clays). The properties and uses of currently worked deposits are discussed and some possible future uses of unworked deposits are mentioned.

Phalen, W. C. and L. Martin


A general survey was made of the geology and mineral resources of the Johnstown Quadrangle in southwest-central Pennsylvania. This
quadrangle lies mainly in Cambria County. Included in the survey of mineral resources were the clay and shale deposits of the area. Known deposits of flint clays, plastic clays (including fire clays) and shales were investigated. The location, general properties and uses of these clays and shales are discussed and a number of chemical analyses tabulated.

Richardson, G. B.

"Description of the Indiana Quadrangle," U.S. Geol. Surv. Folio No. 102 (1904)

A survey was made of the geology and mineral resources of the Indiana Quadrangle in Indiana County, Pennsylvania. Included in the survey of mineral resources were the fire clay and shale deposits of this area. The locations, properties and uses of known deposits are discussed.

Ries, H. and W. S. Bayley


This survey of high grade clay deposits of the Eastern United States includes a general discussion of their uses and more specifically, past, present, and possible future uses of the deposits. The sections on Pennsylvania include deposits of kaolins throughout the state. Deposits in Delaware, Cumberland, Lancaster, Huntingdon, Blair and Centre Counties are mentioned.

Shaw, E. W., E. F. Lines and M. J. Munn

"Description of the Foxburg and Clarion Quadrangles," U.S. Geol. Surv. Folio No. 178 (1911)

A survey was made of the geology and mineral resources of the Foxburg and Clarion Quadrangles in western Pennsylvania. Included in the survey of mineral resources were the known clay and shale deposits of this area. The locations, properties and uses of these deposits are discussed. The clays found in this area are the Mercer, Brookville, Clarion, Kittanning and Freeport. Two chemical analyses are included.
Stone, R. W.


A general survey was made of the geology and mineral resources of the Elders Ridge Quadrangle located in central-western Pennsylvania. Included in the survey of mineral resources were the fire clays, potter's clay and shale found in this area. The locations, properties and uses of these materials are discussed.

Stone, R. W.


A general survey was made of the mineral resources of the Elders Ridge Quadrangle in central-western Pennsylvania. This quadrangle lies mainly in Armstrong and Indiana Counties with a small section in Westmoreland County. In the course of this survey, the clay and shale deposits of the area were investigated. Data is given on the properties and commercial uses of a number of these deposits and one chemical analysis is tabulated.

Stose, G. W.


A survey was made of the siliceous clays mined in the area of South Mountain near Carlisle, Pennsylvania. The topography, geology, mode of occurrence and distribution of the clays are discussed. The mines and plants working the clays were visited and their processes are described. The clays have been used in the manufacture of paper, brick and tile. Further uses are mentioned.

Stose, G. W.


A survey was made of the geology and mineral resources of the Mercersburg and Chambersburg Quadrangles in south-central Pennsylvania. Included in the survey of mineral resources were the clay deposits of the area. Known clay deposits were investigated and locations, general properties and uses of these clays are given. One chemical analysis is tabulated.
"Description of the Fairfield and Gettysburg Quadrangles," U.S. Geol. Surv. Folio No. 225 (1929)

A survey was made of the geology and mineral resources of the Fairfield and Gettysburg Quadrangles in south-central Pennsylvania. Included in the survey of mineral resources were the clay and shale deposits of this area. Known deposits of clays and shales used mainly in the production of brick, paper and tile were investigated and the locations and general properties are given.


A general survey was made of the geology and mineral resources of the Middletown Quadrangle. This quadrangle lies in south-eastern Pennsylvania and comprises parts of Lebanon, Dauphin, Lancaster, and York Counties. The clay deposits of this area were included in the survey of mineral resources. The clays of this area are mainly used in building bricks. However, one deposit of a white clay is used in foundry sands. Locations and uses of known deposits are described.

"Description of the Beaver Quadrangle," U.S. Geol. Surv. Folio No. 134 (1905)

A survey was made of the geology and mineral resources of the Beaver Quadrangle in western Pennsylvania. Included in the survey of mineral resources were the clay and shale deposits of this area. Known deposits of the Brookville, Lower and Middle Kittanning, Lower and Upper Freeport, Clarion and Bolivar fire clays, and the shales of the Allegheny and Conemaugh Formations were investigated. The locations, general properties and uses of these clays are given. Nine Chemical analyses of various clays are tabulated.


A general survey was made of the geology and mineral resources of Beaver Quadrangle in southern Beaver and northwestern Allegheny Counties. Included in the survey of mineral resources were the
clay and shale deposits of the area. Known deposits were investigated and the general physical properties and a few specific chemical analyses are listed. The commercial uses of these clays and shales are discussed.

Publications of the United States Bureau of Mines

Conley, J. E., R. A. Brown, F. J. Cseruenyak, R. C. Anderberg, J. J. Kandiner, and S. J. Green


The possibility of producing metallurgical grade alumina from high-iron Pennsylvania diaspore clays using a lime-soda ash sinter method was investigated. The high-alumina clays used were from the Curwensville and Morgan Run Districts of Clearfield County. The method consists of sintering the ore with limestone and soda ash and then dissolving out the soluble aluminum compounds from the insoluble silica compounds. Final results showed that 87 to 90% recovery was possible at a projected cost of $42.15 per short ton.

Sanford, R. S.


Samples of high-alumina, Pennsylvania clays were investigated to determine the feasibility of producing metallurgical alumina from them. A sample for beneficiation tests was obtained near Curwensville in Clearfield County. Chemical analyses were run for 250 samples from the Hazard Road, Gableton Fields and Rock Cabin Fields areas of Clinton County. Using the limestone-soda ash sinter method, 87% to 90% recovery of alumina was possible. Background data on the location, physical features, history, and description of the deposits is also included.
Schurecht, H. G.


Eleven samples of stoneware clays were obtained and tested. Nine of the clays were from Ohio and two from near New Brighton, Beaver County, Pennsylvania. Properties measured were fired modulus of rupture, fired shrinkage and fired porosity. Graphs of these properties vs. temperature are presented. Some geological data is also included.

Publications of the Pennsylvania Geological Survey

Butts, C., F. M. Swartz and B. Willard


A survey was made of the geology and mineral resources of the Tyrone Quadrangle which consists mainly of northwestern Huntingdon County with small sections of Blair and Centre Counties. The white clay deposits were investigated. The locations and some of the properties of known deposits are discussed.

De Wolf, F. W.


A survey of the geology and mineral resources of the New Castle Quadrangle was made. The Quadrangle consists of the southern section of Lawrence County and the northern section of Beaver County. The clay and shale deposits were included. Known deposits were investigated as to their location and general properties and any commercial uses are cited.

Flint, N. K.


A survey of the geology and mineral resources of the southern section of Somerset County included the clay and shale resources.
Known deposits were investigated as to geological occurrence and commercial uses. The physical properties of three clay samples are tabulated.

Graeber, C. K. and R. M. Foose


A survey was made of the geology and mineral resources of the Brookville Quadrangle. This quadrangle consists mainly of the west central section of Jefferson County with 4 small sections of Clarion County. The clay and shale deposits of the area were included. Known deposits of clay and shale were investigated for chemical and physical properties and commercial uses. The physical properties of twelve samples of shale are listed with a number of chemical analyses.

Hickok, W. O. IV and F. T. Moyer


A survey of the geology and mineral resources of Fayette County was made. Known deposits of clays and shales were investigated as to physical and chemical properties and commercial uses. Data for a number of samples from various locations is included.

Hughes, H. H.


A survey of the geology and mineral resources of the Freeport Quadrangle was made. This Quadrangle consists of the northern section of Westmoreland County and the southwestern corner of Armstrong County with small sections of Butler and Allegheny Counties. The clay and shale deposits were included. Known deposits were investigated as to chemical and physical properties and commercial uses. The chemical and physical properties of eleven clay samples are presented as are vertical sections of thirty-two drill cores.
Johnson, M. E.


A survey of the geology and mineral resources of the Pittsburgh Quadrangle was made. This Quadrangle consists mainly of the southeastern corner of Allegheny County. The clay and shale deposits were included. Known deposits were investigated as to physical properties, location, and commercial uses. A number of chemical analyses are given.

Johnson, M. E.


A survey of the geology and mineral resources of the Greensburg Quadrangle was made. This Quadrangle consists mainly of the western section of Westmoreland County with a small section of Allegheny County. The clay and shale deposits were included. Known deposits were investigated as to chemical and physical properties and commercial uses. Chemical analyses of five samples are presented as are vertical sections of 19 drill cores.

Leighton, H.


Three hundred and ninety samples of clay from ten counties in southwestern Pennsylvania were sampled and tested. The counties include Allegheny, Armstrong, Beaver, Butler, Fayette, Greene, Indiana, Lawrence, Washington, and Westmoreland. Physical tests on the raw clay, burning tests, and chemical analyses were made. The geological relations of the clays and shales and the clay resources of each county are discussed. Recommendations are made for possible future uses of the clays tested.

Leighton, H.


Many Pennsylvania clays were sampled and tested, mainly from the central and south central counties. The samples were of clays in use or of clays readily available for use. Chemical analyses, burning tests, and physical property measurements are presented. Past and present and possible future uses of the clays are discussed.
Miller, B. L.


A survey was made of the clay and shale deposits of Lehigh County, in Eastern Pennsylvania. The materials found in this area are clays residual from limestone, clays associated with limonitic iron ores, white clays and Martinsburg shales. Some past uses of these clays are discussed.

O'Neill, B. J., D. M. Lapham, M. G. Jaron, A. A. Socolow, R. D. Thomson and H. P. Hamlin


Tests were made on 151 samples from 41 counties and 51 geologic units. Of these samples 137 were potentially useful for one or more of the following: Brick, decorative brick, tile, floor tile, drain tile, chimney flue tile, refractories, lightweight aggregate, artware, pottery, filler, and pigmenting material. Rotary kiln and/or sintering tests were made on 25 samples of promise as lightweight aggregate. For each of the 151 samples the following are reported -- (a) unfired properties, (b) fired properties, (c) proportions of quartz, mica, kaolinite, feldspar, and chlorite-vermiculite-montmorillonite estimated by quantitative X-ray diffractometry, (d) proportions of 12 major elements determined by wet chemical analysis, (e) relevant geologic data. The most important variables for predicting potential uses were, in order of decreasing significance -- (1) rock type, (2) mineralogy, (3) chemistry, (4) unfired properties. In evaluating samples for decorative brick, refractories, and rotary kiln lightweight aggregate, the following were especially useful -- quantitative determinations of quartz, mica, kaolinite, total Fe, Fe$^{3+}$/Fe$^{2+}$ ratio, K/Na ratio, CO$_2$, and possibly pH and water of plasticity.

Shaffner, M. N.


A general survey was made of the geology and mineral resources of the Smicksburg Quadrangle which includes northwestern Indiana County, southwestern Jefferson County and 4 small sections of eastern Armstrong County. The clay and shale deposits were included. The chemical and physical properties of known deposits were investigated and a number of vertical sections of these deposits are included in this report.
Shaffner, M. N.


A survey was made of the geology and mineral resources of the New Florence Quadrangle which includes northeastern Westmoreland County, southeastern Indiana County and small sections of Cambria and Somerset Counties. The clay and shale deposits were included. The general physical and chemical properties for a number of samples are listed.

Shaw, J. B.


Eighty-one samples of fire clay from Pennsylvania were tested. The samples were mainly from Centre, Clearfield, Clinton, Fayette and Somerset Counties but many other counties were represented. All sample locations are given as is a general description of the clay deposit and any commercial exploitation. Properties measured were water of plasticity, slaking time, drying shrinkage, P.C.E., firing shrinkage, fired porosity and fired specific gravity. All fired properties were measured over a range of temperatures. Chemical analyses were made of 48 of the samples.

Stone, R. W.


A survey of the geology and mineral resources of Greene County included clays and shales. Known deposits were investigated as to physical and chemical properties and commercial uses. Data for eight shales, sampled at various locations throughout the county, is included.

Stose, G. W.


The clay and shale deposits of Adams County in south-central Pennsylvania were investigated. Clays suitable for use in paper, paint, tile and brick production occur. Past, present and possible future uses of available deposits are discussed. One chemical analysis is given.
Theses of The Pennsylvania State University

Banerjee, S. P.

"Rheology of Hard Shale," M.S. Thesis, Department of Material Sciences (Ceramic Science Section), Penn State Univ. (1970)

An analyzed shale of poor fabrication behavior from Watsontown, Pennsylvania, contained cemented aggregates of quartz, mica, hematite, etc., and released relatively few micaceous flakes during fine grinding. However, suspensions of shale particles in electrolyte solutions showed the yield values and thixotropy commonly exhibited by more plastic clays. Shale pastes, with or without dispersants or flocculants, including sodium hexametaphosphate or polyethylene oxide, showed yield values related to liquid-content by a well-known exponential expression, preferably modified to allow for the void space between the particles at their closest approach. Plasti-corder curves showed unusual double peaks associated with the segregation and aggregation of the finer particles. Plasticity might be improved by the successive additions of a dispersant and a flocculant, such as sodium hexametaphosphate and polyethylene oxide. The micro-structure of extruded columns was compared to that of more plastic clays.

Bratton, R. J.


Seven high-alumina clays from the Morgan Run and Anderson Creek Areas near Clearfield in Clearfield County were sampled and tested. Spectrochemical, P.C.E., and fired shrinkage and porosity data were obtained, together with quantitative X-ray mineralogical analyses. The mineralogy was correlated with the phases formed between 1000°C and 1500°C. The amount of mullite formed was found to depend on the source of Al₂O₃, not the amount available, at temperatures up to 1300°C. Above this temperature the amount of mullite was directly dependent upon the amount of Al₂O₃. The measured ceramic properties (shrinkage and porosity) were correlated with the mineralogical and chemical data.
Cohen, S. M.


Tests were made on three Pennsylvania siliceous white clays to determine the optimum conditions for the flotation of the residual white clay from the quartz impurities. Various cationic alkyl amine collectors (having different carbon chain lengths) were evaluated and classified. Primary dodecylamine was found to be the best collector for clays. Clays suitable for various commercial applications, mainly as fillers, were obtained.

Erickson, E. S.

"Mineralogical, Petrographic, and Geochemical Relationships in some High-Alumina and Associated Claystones from the Clearfield Basin, Pennsylvania." Ph.D. Thesis, Department of Geochemistry and Mineralogy, Penn State Univ. (1963)

High-Alumina clays from Clearfield County, Pennsylvania, were characterized as to mineralogy, petrography and geochemistry. All samples were from the two major high-alumina clay deposits of Clearfield County -- the Morgan Run and Curwensville Deposits. Also investigated was the compositional variation, vertical and/or lateral, within the clay deposit. This was found to be due to the intermixing, in varying proportions, of three types of material - detritus, kaolinitic colloidal precipitates and high-alumina gels. A number of conclusions are drawn as to the origin and geological environment of these deposits.

Fetterman, J. W.


Optimum conditions for removing alumina from a high alumina diaspore clay from central Pennsylvania by using an ammonium sulfate process were determined. The individual minerals occurring in the clay (Kaolinite, Diaspore and Boehmite) were first investigated to determine their behavior in this process. Alumina recovery varied from a maximum of 95% for Kaolinite to 83% for Diaspore. The naturally occurring clay behaved similarly to the individual minerals but approximately 20% more ammonium sulfate was necessary due to the iron present.
Hetstek, H.


Twelve building brick clays from southeastern Pennsylvania were investigated as to clay mineral content, using differential thermal analysis and X-ray diffraction techniques. The major clay minerals were kaolinite and illite. Differential thermal curves of prepared mixtures showed that individual components of clay mineral mixtures are not always discernible. Some data are given for illite isolated from two of the samples.

Hirsh, W.

"Removal of Iron from Pennsylvania Clays by Acid Leaching," M.S. Thesis, Department of Mineral Preparation, Penn State Univ. (1966)

Procedures for selectively extracting iron from Pennsylvania high alumina clays were investigated. The purpose was to upgrade these clays to make them more suitable for production of high-purity alumina. The high-alumina clay used was obtained near Curwensville, Clearfield County, Pennsylvania. Leaching with HCl was found to be the most effective in reducing the iron content without affecting the alumina content. Reductions in iron content as high as 94% were obtained. Sulfuric acid was less effective.

Hutchison, C. R.


Factors affecting the properties of semi-dry pressed samples of lower Kittanning Clay were investigated. The samples were obtained one mile south of Curwensville, Pennsylvania, and were used "as mined" without any treatment other than grinding. Studied was the effect of initial water content and fabricating pressure on the apparent porosity, modulus of rupture, bulk density, linear shrinkage and thermal expansion of test-pieces heated at 110°C, 650°C, and 1210°C. The effect of microstructure on the measured properties of the test-pieces was also investigated.
McGill, H. N.


The geology and mineralogy of the Lower Kittanning Underclay just south of Curwensville in Clearfield County was studied. Differences between the upper underclay, thought to be transported, and the lower underclay, considered to be residual, were evaluated to differentiate between them. The SiO₂/B₂O₃ ratio was found to be the best indicator of the variation in weathering and the Al₂O₃/B₂O₃ ratio the best indicator of the variation in original composition of the sedimentary material.

Ormsby, W. C.

"Beneficiation of a Highly Siliceous White Clay from Alexandria, Pennsylvania," M.S. Thesis, Division of Ceramics, Penn State Univ. (1951)

A white clay from Alexandria, Pennsylvania, was investigated to determine if it could be upgraded to compete with clays from the southeastern United States. Flotation studies showed that it was not commercially feasible to beneficiate this clay by this technique. Maximum refinement resulted in a concentrate containing 77.5% clay, with a clay recovery of only 24%. This was believed to be due to the intimate association of clay and quartz.

Reagan, C. J.

"Effects of Additions of Chemicals on Some of the Properties of Clays," M.S. Thesis, Department of Mineral Technology, Penn State Univ. (1948)

The effect of various chemical additions on the apparent viscosity and other properties of three representative Pennsylvania brick clays was studied. The locations of the clays are not given. The apparent viscosity was measured with a Stormer viscometer and was considered to be related to the workability. Other properties measured were the pH, water of plasticity and the dried and fired properties of extruded test pieces. Both acids and bases acted as flocculants or deflocculants depending upon the amount added and the clay used. Their other effects upon the dried and fired properties are noted.
Rosenkrans, R. R.

"Correlation Studies of the Central and South Central Bentonite Occurrences," M.S. Thesis, Department of Geology and Mineralogy, Penn State Univ. (1933)

A detailed study of the stratigraphy and petrography of the Bentonites of the central and south central counties of Pennsylvania was made. The twelve beds studied varied from near zero to a maximum of ten inches in thickness. In the course of this study a large number of new outcrops were discovered and reported. No essential differences in the character of the twelve beds studied were found.

Sutton, W. H.


Four shales from near Watontown, Pennsylvania, were sampled and the mineral constitution and ceramic properties determined. These properties were particle size distribution, plasticity, weight loss and shrinkage upon drying and firing, modulus of rupture and color change upon firing. The minerals in the shales were mainly quartz and hydrous mica, approximately 10% chlorite, with Goethite, haematite, TiO$_2$, and organic matter. Very little correlation was found between the ceramic properties and the mineral composition.

Weaver, C. E.

"Mineralogy and Petrology of Some Paleozoic Clays from Central Pennsylvania," Ph.D. Thesis, Division of Mineralogy, Penn State Univ. (1952)

Twenty-eight samples of Ordovician K-bentonite from central Pennsylvania were examined and found to be randomly interstratified expanded and non-expanded 2:1 layers. Chlorite was also identified in many of the samples. A direct correlation was found between the percentage of K-bentonite present and the percentage of non-expanded layers. The clay is believed to be an alteration product of volcanic glass.
Weitz, J. H.


Samples of the Mercer fire clay were examined in the field and studied in the laboratory using x-ray diffraction, differential thermal analysis and petrographic methods to determine the mineralogical and geological characteristics. The most abundant minerals were kaolinite, diaspor, and boehmite. A theory for the origin of this clay is presented but a number of other theories are also considered. Present and past mining activity is described and suggestions for future exploration are made.

Williams, E. G.


Detailed lithologic and paleontologic studies of 90 measured sections in the Clearfield Basin and of 50 sections of the Clarion Formation in the Brookville Basin were made. Refractory clays in the Clearfield Basin occur beneath the Brookville A-1 and A-2 and Lower Kittanning coals. No refractory clays were observed in the Pottsville rocks of the area studied. Shales have mainly quartz, illite, kaolinite and minor chlorite. The proportion of illite to kaolinite decreases as organic matter increases. Underclays are much more variable in clay mineral composition than shales. Lower Allegheny underclays vary from highly illitic to highly kaolinitic even in a single vertical section. Upper Allegheny underclays are predominantly illitic and calcareous. No chlorite was detected in underclays. Underclays have a disorganized fragmental texture while shales show a preferred orientation of the mineral platelets.
Bates, T. F.

"Selected Electron Micrographs of Clays and Other Fine-grained Minerals," College of Mineral Industries, Penn State Univ., Experiment Station Circular No. 51

Clay minerals from Pennsylvania localities are among those depicted, over the figure numbers following -

2. Dickite, Schuylkill.
5. Kaolinite, Williamsburg.
9. Kaolinite, Mt. Holly Springs, probably formed by weathering of feldspar in arkose, with a form believed to result from decomposition or skeletal growth.
14. Kaolinite, Elmora, in fracture surface of flint-clay (at base of upper Kittanning coal) which gives a kaolinite X-ray pattern but has little well-defined crystal form.
15. Kaolinite, in fracture surface of chert from Woodbury clay pit, Williamsburg, as well-defined clustered crystals.
29. Halloysite tubes and kaolinite as hexagonal crystals varying to skeletal flakes, with needles of hydrated iron-oxide, Mt. Holly Springs.
52. K-bentonite, Oak Hall, a mixed-layer flakey illite-montmorillonite.
53. Illite, State College, as irregular lath-shaped and equidimensional plates, from thin layers and pockets in the Tuscarora quartzite.
54. Illite, State College, from the Oswego Formation, having particles similar to 53 but with a high degree of preferred orientation.
55-56. Illite, State College, showing, by dispersion and replica techniques, the lath-shaped characteristics of much of the illite in the clay fraction of the Tuscarora and Oswego Formations in central Pennsylvania.

Rosenkrans, R. R.

"Correlation of the Central and South Central Pennsylvania Bentonite Occurrence," Penn State College Mineral Industries Experiment Station Technical Paper II (1934)

Twelve beds, maximum thickness 10 in. and often much thinner, are described with chemical and petrographic data. They appeared to be similar in characteristics. Some new occurrences are included. Six beds in the Salona Formation were traced throughout an area 25 miles wide and over 110 miles long. Six pre-Salona age beds were recognized and correlated throughout part of the area.
Shaw, J. B.

"The Ceramic Industries of Pennsylvania," Penn State College Mineral Industries Experiment Station Bulletin 7 (1930)

Ceramic industries (structural products, whiteware, refractories, electro-ceramics, glass, abrasives, cement, metal enamels, etc.) are described with little reference to the location of raw materials. Flow sheets, photographs and diagrams of plant operations, and a plant location map are included. There are references to early theses on raw materials, etc.

Sun, Shiou-Chuan, Tze Chao, W. Hirsh, and B. A. Freed


Alumina was successfully extracted from a kaolinitic flint clay containing Al\(_2\)O\(_3\) 49.05%, SiO\(_2\) 40.90%, Fe\(_2\)O\(_3\) 3.01%, S 0.07%, loss on ignition 13.80% (750°C., 30 min.) by selective hydrochloric acid leaching of iron, alumina extraction by sulfuric acid or gaseous SO\(_2\) and electrolytic removal of iron from the aluminum sulfate leach liquor. The clay was from a coal mine near Grampian. The account is based on listed theses.

Williams, E. G. and J. C. Griffiths


High alumina clay in western Pennsylvania occurs only where the Upper Connoquenessing sandstone is absent and is thought to be related to topographic highs developed in Lower Connoquenessing times. In clay-bearing, as opposed to barren areas, the upper 5 feet of the Lower Connoquenessing sandstone contains much quartz and rounded tourmaline. When prospecting for high alumina Mercer clay, this upper 5 feet should be sampled and certain critical variables related to quartz or to tourmaline characteristics, and preferably to both, assessed. When these variables are significantly developed, the chances of locating a topographic high, possibly accompanied by high alumina clay, are better.
Williams, E. G. and R. P. Nickelsen

"Correlation of the Pottsville and Lower Allegheny Series in Parts of Clearfield and Centre Counties," Penn State Univ. Mineral Industries Experiment Station Bulletin No. 71, pp. 37-50 (1958)

New information on the classification and correlation of the Lower Allegheny and Pottsville series in Clearfield County follows detailed stratigraphic and paleontologic studies. The Brookville and Clarion 1, 2 and 3 coals have been recognized and traced throughout the counties. Refractory clays occur beneath the Brookville, Clarion No. 1 and Lower Kittanning coals. Maps and vertical sections are included.

Papers Published in Various Journals

Ashley, G. H.


The raw materials for fire brick production mined in Pennsylvania are discussed (soft fire clay, flint clay and ganister rock). Data on their properties, geological occurrence, distribution and uses are included. Included is data from unfired and fired property tests on 18 samples of clay from Clearfield County.

Bonine, C. A. and A. P. Honess


Beds of bentonitic material occur in almost every quarry in central Pennsylvania exposing Middle Ordovician marine limestones. The weathered material is not so water-absorbing as typical bentonites from the western U.S.A. Petrographic data are given for the bentonites, with a chemical analysis of unweathered material from Oak Hill quarry (Lemont member of the Carlin Formation). Six bentonite beds, 1-14 in. thick, occur in the Middle Ordovician limestones of central Pennsylvania. Vertical sections are given for the Union Furnace, Williamsburg and Bellefonte occurrences.
Bratton, R. J. and G. W. Brindley


Seven clays of the Mercer Formation near Clearfield, Pennsylvania, were fired at various temperatures from 1000 to 1500°C. Firing shrinkages or expansions are cited. Chemical analyses, and the quantitative proportions of kaolinite, boehmite, diaspore, and anatase in the raw, and of mullite, oristobalite, and corundum in the fired, clays are given. The proportions were determined by X-ray techniques. The thermochemical reactions during firing are discussed and PCE values given.

Brindley, G. W., D. M. Maroney and S. Udagawa


Sixty clays and shales from the Pennsylvania series in the Clearfield Basin were analyzed semiquantitatively for mineral content. The shrinkage and porosity of fired samples (1100 and 1200°C) were compared with those of artificially prepared mixtures of essentially the same minerals (quartz, kaolinite, and mica). Chlorite or perhaps vermiculite occurred in some samples. Results for the natural clays and prepared mixtures were in general agreement. The amount of mica had a large effect on the fired properties due to its tendency to form glasses.

Degens, E. T., E. G. Williams and M. L. Keith


Most samples were from the Allegheny Series of the first four coal basins west of the Allegheny escarpment in Clearfield and Jefferson counties. Quantitative petrography is given for the Brookville, Lower Kittanning, Middle Kittanning, Upper Kittanning, and Lower and Upper Freeport shales in terms of quartz, mica, matrix, opaques, pyrite, miscellaneous and organics. Clay content varied from 75 to 89%. Seventeen trace elements were determined.
Degens, E. T., E. G. Williams, and M. L. Keith


All samples were from the Pottsville and Allegheny Series of western Pennsylvania and included Brookville fire clay, Brookville shale, Bigler plastic clay, Clarion No. 1 shale, Clarion No. 3 clay and Lower Kittanning underclay. Illite kaolinite ratios and trace element (Ga, Rb, B) content are discussed and explained. The more refractory clays, high in Al, are also high in Ga.

Foose, R. M.

"High Alumina Clays of Pennsylvania," Econ. Geol., 39 557-577 (1944)

The origin, occurrence and geology of the high alumina clays of the Curwensville and Morgan Run Districts (Clearfield County, Pennsylvania) were investigated. These clays were formed partly by the leaching of silica from an initial flint clay and partly by the addition of alumina. The alumina contents varied from 75% to 30% or lower with a corresponding variation in appearance and physical properties. Petrographic data is presented for many samples. Also discussed are current and future commercial possibilities.

Hutchison, C. R. and W. O. Williamson


The material was mixed channel samples from Jeff Thomas strip mine one mile southwest of Curwensville, Pennsylvania. It contained quartz, kaolinite, chlorite or vermiculite, and muscovite or illite. Chemical analyses of material as received and after heating at 450°C are given, with a particle-size analysis. Small rectangular prisms were pressed at 5-13% water at 600-2560 psi. Moist clay and liquid water, expelled between the punch and the die, reduced the water content by up to 2%. Initial water contents of 9% gave minimum apparent porosities and maximum bulk densities and moduli of rupture after heating at 110°C, 450°C and 1210°C. However, prisms made at constant pressure and fired at 1210°C gave low porosities at 7 1/2 and 9% water, the latter percentage giving the smaller porosity. Relatively large porosities appeared at intermediate water-contents and some were greater then at 650°C. Variations in bulk density and modulus of rupture showed comparable behavior.
Keller, W. D.

"Flint Clay and a Flint-Clay Facies," *Clays & Clay Min.*, 16 113-128 (1968)

Flint clay deposits in the United States including Pennsylvania and overseas were investigated to determine their common geological and geochemical background. Studied were the distribution, lithology, mineralogy, refractory properties, chemical composition and occurrence of these deposits. D.T.A., X-ray and chemical data is presented. By correlating the data for the various deposits and using geochemical principles, a theory of the origin of flint clays was postulated. The concept of flint clay as an intermediate in the series between high-silica illitic shales and high-alumina diaspore and boehmite is also discussed.

Williams, E. G.

"Relationship Between the Stratigraphy and Petrography of Pottsville Sandstones and the Occurrence of High-Alumina Mercer Clay," *Econ. Geol.*, 55 1291-1301 (1960)

A stratigraphic and petrographic study was made of 32 sections of the Mercer and Connoquenessing Formations in western Pennsylvania to determine the relationship of deposits of high-alumina Mercer clay to underlying outcropping sandstones. The distribution of the high-alumina clay is believed to be related to ancient topographic highs where flint clay was deposited directly on Lower Connoquenessing sandstone and subsequently leached to form diaspore. The Upper Connoquenessing sandstone was deposited in adjacent topographic lows. The most likely areas for further prospecting for high-alumina Mercer clay would therefore be where the Upper Connoquenessing sandstone is thin or absent.

Williams, E. G., R. E. Bergenback, W. S. Palla, and S. Udagawa


The Pottsville and Allegheny underclays of western Pennsylvania show no chemical or mineral profiles but beds vary among themselves. The Pottsville and Lower Allegheny underclays are highest in illite, chlorite and Fe₂O₃. The high alumina clays of the Pottsville and Lower Allegheny are localized in swammy areas on abandoned clastic wedged fringed by shallow seas. In general, stratigraphic and geographic variation in clay mineral composition was controlled by the chemistry of the depositional environment. Seventy-two samples of underclays and associated shales in the vicinity of Clearfield were analyzed semiquantitatively by X-ray techniques for illite, kaolinite, chlorite and quartz. They were analyzed spectrochemically for SiO₂, Al₂O₃, K₂O, Fe₂O₃, TiO₂ and CaO.
Miscellaneous Publications

Buckwalter, T. V. et al.

Geological Society of America Guidebook for Field Trips. Pittsburgh Meeting (1959)

The itineraries, and geological features examined, were related to central Pennsylvania and the Anthracite Region, the Pennsylvanian of western Pennsylvania, geological formations of the Appalachian Basin, mineral deposits of eastern Pennsylvania, glacial geology of northwestern Pennsylvania, and the engineering geology of the Pittsburgh area. References to ceramic raw materials are incidental, not specific. There are maps and vertical sections including a fold out map of central Pennsylvania.

Hopkins, T. C.

"Clays and Clay Industries of Pennsylvania, I. Clays of Western Pennsylvania (in part)," Appendix to Annual Report of the Penn State College for 1897 (1898)

Clays and clay industries of the Ohio, Monongahela, Youghiogheny and Conemaugh river valleys as far up as Kittanning are described. This includes Allegheny, Westmoreland and Fayette Counties and parts of Beaver, Washington, Greene, Indiana, Armstrong, and Cambria Counties. Photographs of plant operations and maps are included.

Hopkins, T. C.

"Clays and Clay Industries of Pennsylvania, II. Clays of Southeastern Pennsylvania (in part)," Appendix to the Annual Report of the Penn State College for 1898 (1899)

Occurrences of clays, feldspar, and flint, in Philadelphia, Delaware, Chester and Montgomery Counties, and the associated ceramic industries, are described, with maps.