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KANSAS CLAY, DAKOTA FORMATION

BY NORMAN PLUMMER and JOHN F. ROMARY

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KANSAS CLAY, DAKOTA FORMATION

By Norman Plummer and John F. Romary

ABSTRACT

The pre-Greenhorn Cretaceous beds of north-central, central, and southwestern Kansas were investigated to determine the occurrence and ceramic properties of the clay and shale deposits therein, with particular emphasis on the clay deposits of the Dakota formation.

The clays of the Dakota formation are made up of approximately one-third white-firing to buff-firing clays and two-thirds dark buff-firing to red-firing clays. The clay mineral content of these beds is dominantly kaolinite, and the clays definitely are noncalcareous. Ceramic tests and chemical analyses indicate that the white-firing to buff-firing clays may be classed as kaolin, ball clay, plastic fire clay, siliceous fire clay, or highly siliceous fire clay. With the exception of the kaolin deposits the various types of clay occur in enormous quantities. The total tonnage available for commercial use has been estimated to be between 150 and 400 billion tons.

The small beds of kaolin have a pyrometric cone equivalent in some cases as high as cone 34. The other types of clay have a known maximum pyrometric cone equivalent of cone 30. Ceramic properties such as working quality, drying and firing shrinkage, and maturing temperatures are largely determined by particle size and the amount of finely divided quartz in the clays. In general, the plasticity is greater than would be expected due to the relatively small particle size of both clay and quartz and the ease with which the clays disintegrate in water. Working properties are good, and the clays can be dried and fired with a minimum of difficulty from warping, cracking, or incomplete oxidation. Total shrinkage varies from less than 1 percent to nearly 20 percent. Maturing temperatures range from cone 07 to above cone 14. In general, the clays have both a long firing and vitrification range.

The fire clays of the Dakota formation are suitable for use in the manufacture of light-colored structural clay products, refractories, pottery (including porcelain, whiteware, stoneware, earthenware, and art ware), and similar high-grade products. The dark buff-firing to red-firing clays are primarily suited for use in the manufacture of structural clay products, but have a limited value for use in the manufacture of pottery and refractories.

The beds of the Kiowa and Graneros shale formations sampled are nearly identical in ceramic characteristics, and on the whole are of little value for ceramic uses. These shales usually are extremely dense, have high shrinkage values, and tend to bloat on firing. The fired colors are unattractive shades of orange-red or brown. In short, these materials are typical of the poorer quality illite shales. Advantage may be taken of the normally undesirable qualities of these shales, however, in that they are suitable for the manufacture of light-weight insulating blocks and light-weight aggregate.

INTRODUCTION

The earliest human records prove conclusively that clay products were commonly employed in the construction of shelters and for man's everyday tools and utensils some 10,000 years ago. Bricks and pottery of that age have been dug up from the silt of the Nile River bed, where objects made of common metal—had there been any at that time—would have been largely decomposed in a few centuries.

In more modern times, history has shown that when new countries were colonized, the pioneers first built homes from the convenient forests. After a few generations, however, as the forests were cut away, the trend invariably has been to build with the enduring and close-at-hand clay products and stone. Good examples are the countries of Europe, where forest products are at a premium, and where buildings of earth materials are now the rule.

Our country, only 300 years after colonization, is feeling the scarcity and high cost of forest products. The trend here toward greater consumption of clay products for domestic and industrial use is unescapable. It is desirable, too, because a change from the general use of less-enduring wood to wearless, ageless ceramic products indicates the arrival of a more substantial, deeper-rooted phase of our country's development.

It was, in part, recognition of this trend that prompted the Kansas Geological Survey to plan a comprehensive clay investigation. This report, the first detailed study of its kind to be published in Kansas, is the result. Although the State's clay industry was started early because Kansas was poorly forested originally and because natural gas for cheap and convenient firing of local clay materials was discovered during the State's infancy, the industry, which consisted mainly of the production of structural and paving brick and several kinds of tile, had declined. This was due in part to the establishment of the pioneer ceramic industries in central and southeastern Kansas where local clay materials were mainly the red-burning, nonrefractory clays and shales of Pennsylvanian age. A demand was developing for light- or buff-firing clay products. Few local deposits of light-firing clays were known and the opinion had become widespread that no important quantities of light-firing clays were to be found in the State.

During the 1930's, interest in pottery-making, both in Kansas schools and among craftsmen, increased significantly. The Department of Design at the University of Kansas was especially active in stimulating interest in pottery, and in finding light-firing clay for use in pottery and art classes.

Members of the Survey in 1936 and 1937 gathered materials from a wide area, and found that clay samples from deposits of Dakota age in Ellsworth County were of high quality and fired to ivory and buff colors. Both field and laboratory work then began in earnest. A Works Projects Administration program, using 10 to 100 men, made possible the digging of pits for sampling in the field; another WPA project in the laboratory gave much-needed assistance in the preparation of samples for testing. Since 1942, members of the regular staff of the Industrial Minerals Division of the Geological Survey have continued laboratory work and compilation of this bulletin along with their other duties.

The detail to which we have gone in describing the new clays, their locations, testing, and utilization, has been determined by the nature and number of inquiries, by the importance of the findings, and by the fact that no comprehensive report on Kansas clays has previously been published. The intent of making the bulletin much more than merely a record of results obtained has been deliberate. In its present form, the bulletin should be of greater utility to Kansas industry and craftsmen and to Kansas students who may be interested in the clays investigated.

Some work remains to be done on samples of the Dakota material, and detailed reports will be issued from time to time on these and other clay and shale deposits of Kansas. A few short reports and papers on Kansas clays appear in the literature. They are listed in the bibliography.

SCOPE OF THE WORK

The field investigation covered the entire outcrop area of the Cretaceous rocks below the Greenhorn limestones in north-central, central, and southwestern Kansas. The work covered all or parts of Ellsworth, Lincoln, Ottawa, Cloud, Washington, Ford, Hodgeman, Barton, Rice, McPherson, Saline, Russell, Clay, Republic, Kiowa, Pawnee, Edwards, and Clark Counties (Fig. 1).

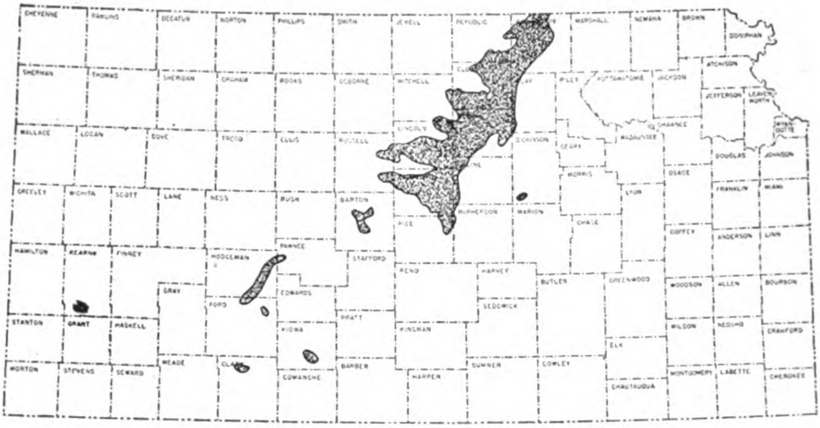


Fig. 1.—Map showing outcrop area of the Dakota formation covered in this investigation.

DEFINITION OF CLAYS

The term "clay" is applied to a wide variety of earthy materials, ranging from crudest mud to pure kaolin included in fine porcelain mixtures. Clay is so familiar that the term has come to connote "common." From our experience with clay roads we are familiar with the properties of clay that cause it to become a sticky gummy mass when wet, and to harden into ruts and clods when dry. If we add to this the observation that if the dry clods are heated to at least redness they become permanently hard, and can no longer be disintegrated if placed in water, we are aware of the essential physical properties of clay. In order to clarify the terms most widely used to describe types of clays we are including a partial list of the definitions which have been recommended for adoption by the Committee on Geological Surveys of the American Ceramic Society (Ries, and others, 1939, pp. 213-214). Most of the terms are descriptive of types of clays used in the ceramic as well as other industries. The list of terms is arranged alphabetically rather than according to uses, properties, or geologic occurrence for the reason that many of the names can be placed in more than one group. For example, ball clay, plastic fire clay, pottery clay, and enamel clay are terms which conceivably could be applied to a single sample of clay.

Clay: A naturally occurring earthy aggregate in which hydrous silicates of alumina usually predominate. It is usually plastic when sufficiently pulverized and wetted, rigid when dry, and becomes steel-hard when fired at a sufficiently high temperature.

Ball clay: A very plastic fine-grained refractory clay firing usually to a white or ivory color but sometimes light buff. It commonly fires to a low-absorbent body between cones 5 and 10, but as high as cone 15 in some cases. It remains light in color and does not over-fire at whiteware temperatures. Its function is chiefly that of a bonding or suspending agent.

Bond clay: A clay of high plasticity and high dry strength which may or may not be refractory and is used to bond nonplastic materials.

Calcareous clay: A clay containing appreciable amounts of calcium carbonate. If the quantity of $CaCO_3$ exceeds that of Fe_2O_3 the clay fires to a cream color.

China clay: A term originally applied to the beneficiated purified kaolin mined in Europe, but now applied to all beneficiated kaolin.

Diaspore clay: A clay usually containing more than 60 percent alumina with the mineral diaspore often in shotlike particles or "oölites." There may be some gibbsite or cliachite present.

Enamel clay: A finely divided, very plastic, naturally fine-grained clay of low iron content and sufficiently high powers of suspension so that when properly dispersed in water it can be used to hold enamel frits in suspension. It also produces opacity in enamels.

Fire clay: A clay of either sedimentary or residual character which has a P. C. E. of not less than cone 19. It may vary in its plasticity or other physical properties and while it often fires to a buff color, it does not necessarily do so. It is recommended that clays with a P. C. E. of 19 to 26, inclusive, be called "low heat duty fire clays," and that fire clays with a P. C. E. of cone 27 or higher be designated as "refractory."

Filler clay: Any clay used in a crushed or ground state for purposes other than the production of ceramic materials or products, and generally behaving as an inert ingredient.

Flint clay: A clay, usually refractory, that has a dense structure, moderate hardness, and conchoidal fracture. It is difficult to slake and very low in plasticity under usual working conditions.

Kaolin: A white-firing clay which in its beneficiated condition is made up chiefly of minerals of the kaolinite type. Two types of kaolin may be recognized.

(a) Residual kaolin. A kaolin found in the place where it is formed by rock weathering.

(b) Sedimentary kaolin. A kaolin which has been transported from its place of origin. Sedimentary kaolins show more pronounced colloidal properties than residual kaolins.

Loess: A clayey (argillaceous) silt which may vary greatly in composition, especially the amount of free silica and calcium carbonate. It is usually regarded as a wind-deposited material.

Marine clay: A clay which has been accumulated as a sediment on the sea floor. Such clays do not include estaurine or sea-delta deposits, but they may grade into them.

Modeling clay: A clay suitable for use, in a plastic condition, for sculpture and similar purposes.

Paper clay: A white clay, very low in free silica, and usually having a small particle size as marketed. Because of its high retention, color, and suspending properties, it is used for filling or coating paper. Most paper clays as put on the market are beneficiated products.

Potter's clay: A plastic clay that can be easily shaped into objects on the potter's wheel. The term is becoming obsolete commercially.

Refractory clay: Any clay showing a P. C. E. of not less than cone 27.

Sagger clay: A fire clay or ball clay suitable for sagger manufacture and of suitable bonding quality. It may resemble a bond clay in plasticity but it contains more impurities and may be more siliceous.

Shale: A consolidated or indurated clay, usually having a laminated structure. All gradations may be found between a true shale and a plastic clay.

The terms "shale clay" or "clay shale" are sometimes used interchangably to designate a material intermediate between shale and clay.

Siliceous clay: A clay containing appreciable content of free silica in particles which may or may not be visible to the naked eye.

[A. S. T. M. Standard C 27-20 defines a "siliceous clay fire brick" as one having a silica content of 70 percent or more, and a "clay fire brick" as one having a silica content less than 70 percent. In this report siliceous fire clays are defined as those having a silica content of 70 percent or more and plastic fire clays as those having a silica content of less than 70 percent if the clay has sufficient plasticity to be so classed as plastic.]

Slip clay: A clay or shale which fuses completely between cones 5 and 10 and can be used alone as a natural glaze.

Stoneware clay: A clay suitable for the manufacture of stoneware; it possesses good plasticity, vitrifies between cones 4 and 10, and has a long firing range. The color (on firing) is buff to gray.

Terra cotta clay: Any clay of suitable plasticity and working properties for the manufacture of terra cotta such as vases, statuary, or architectural shapes. It should also have good plasticity. Much of that used in the United States is of the stoneware or fire-clay type.

Underclay: A clay occurring under beds of coal or the horizon of a coal bed; usually characterized by lack of bedding, slickenslide surfaces, and the presence of carbonaceous material.

Wad clay: A clay of high plastic tensile strength and plasticity which can be used to make a joint between saggers and other refractory material.

ACKNOWLEDGMENTS

The extensive pit sampling program of the Dakota clays would have been impossible without the active assistance of the Federal Works Progress Administration. During 1938, 1939, 1940, and 1941 this Federal agency furnished labor for the excavation of test pits under our supervision and during part of this time also furnished labor for the assistance of handling samples in the laboratory. We express our thanks to the many land owners who granted us permission to work on their property and in other ways aided the field work. Other divisions of the State Geological Survey, particularly the chemical laboratory, rendered invaluable assistance throughout the progress of this investigation.

GENERAL DISCUSSION OF CLAY

DEVELOPMENT AND USES OF CLAY PRODUCTS

History of clay products.—Clay has been used for thousands of years to make things for the convenience of man. Probably the first products were unfired adobe bricks of mud and straw. Fired bricks more than 10,000 years old have been found 30 feet below the level of the Nile Valley, and fragments of pottery that are approximately the same age have been unearthed. More perfect types of pottery as well as the use of glazes were developed in Egypt as early as 3000 to 1700 B.C. On Egyptian tombs of this period were found pictures portraying the making of pottery, including the firing of it in kilns.

The ancient cities of Ninevah and Babylon were built largely of bricks. Their ruins today are an accumulation of yellowish-white bricks, many of which are covered with colored glazes. The Chaldean and Assyrian potters made tombs constructed entirely of one large piece of fired clay ware—pieces so large that they would test the skill of the best craftsmen of today. The well-preserved records of ancient times we owe to the potters' kilns of Babylon and Assyria. These were inscribed on clay tablets and baked. Not only are the inscriptions well preserved, but also even the fingerprints of the maker are often found on the ancient clay tablets.

A few years ago a succession of buried cities was discovered on the river Indus in India. The earliest of these cities, estimated to be at least 5,000 years old, was built of well-fired bricks. The city was laid out in blocks with straight and well-planned streets.

The Chinese also have a long and honorable record in pottery making. The first pottery noted in their literature was made between 2700 and 2600 B. C. However, the impermeable porcelain and stoneware to which we have given the name "china" was not made until about 200 B. C. It reached its present quality of perfection in the fourteenth century.

American pottery making dates back at least to 1000 B. C. and probably much earlier. The Aztecs manufactured "terra cotta" as early as this and when conquered by the Spanish had constructed brick buildings. Kansas Indians made pottery long before Columbus discovered America as indicated by the finding of well-made pieces of pottery in their burial pits.

Value and importance.—Without the products made from clays many of our major industries would be unable to operate. Fire-clay bricks or more complex products made of fire clay are used for furnace and boiler linings in power plants, refineries, smelters, ships, locomotives, and various processing plants. High tension insulators for electrical transmission lines are made most economically and satisfactorily from clay or porcelain, which is composed of a mixture of minerals, the chief ingredient of which is clay. These products range from the huge insulators used on power lines to the spark plugs in automobiles. Brick and tile manufacture remains an accepted standard in buildings for permanent construction. Cement and concrete have replaced structural clay products for many of the former uses, but the present rate of consumption of concrete as compared to brick and tiles is probably fairly stable. An increase in the use of materials made from both clay and concrete is to be expected, however, owing to the depletion of our forests. Although this depletion was a cause for concern before World War II, the greatly increased consumption during the war has made the situation much more serious.

Efforts on the part of brick and tile manufacturers in Iowa to produce hollow tile units suitable for low-cost farm construction, and a well-organized advertising campaign have greatly increased the consumption of those products in that state. Technical advances in this and other branches of the industry, which will better adapt the product to the needs of the consumer, can be expected to result in an increased demand.

Many products made from clay, other than those already mentioned, play important parts in our daily lives. Most of the dinnerware used on our tables, stoneware used in the chemical industry, art pottery, sanitary porcelain, and bathroom and kitchen tiles are made chiefly from clay. Although the clay-products industry is small by comparison with many of our major industries, its value commercially is of considerable importance. The all-time record for total value of clay products manufactured in the United States was reached in 1926 when the production attained a valuation of $458,900,000. The value of the products manufactured in 1929 was only $406,500,000, and in 1932 the value of such products sank to a low of $96,700,000. The total value had risen to $217,600,000 in 1936, and the trend was generally upward until the beginning of World War II. During the war the relative value of the various types of clay products changed radically due, for example, to the increased demand for refractories and the shortage of labor and fuel in the structural clay products industries. Thus during the war the production of refractories increased and structural clay products decreased. Since the end of the war this tendency has been reversed.

The diversity of clay products and the relative value of each are shown in Table 1 (Chute, 1939) for the year 1936 because recent statistics on total production in terms of the total value of the finished products are not available. The Bureau of Mines Minerals Yearbook publishes only the tonnage and value of raw clay produced, which is misleading because of the wide spread

TABLE 1.—*Value of clay products produced in the United States in 1936* (Chute, 1939, p. 26)

Product	Value in millions of dollars	
Pottery		
Whiteware	23.7	
China and hotel ware	8.7	
Red earthenware	1.8	
Rockingham, yellow and stoneware	1.6	
Electrical porcelain	15.8	
Vitreous sanitary ware	18.1	
Semi-vitreous sanitary ware	0.4	
Miscellaneous pottery	11.2	
Total pottery		81.3
Clay products other than pottery		
Miscellaneous	9.3	
Common brick	30.1	
Paving brick and block	2.3	
Face, fancy, and enameled brick	12.7	
Hollow building tile and fire-proofing	8.9	
Roofing, floor, and ceramic mosaic tile	5.8	
Wall and Faience tile	10.2	
Architectural terra cotta	2.6	
Drain tile	2.5	
Sewer pipe	12.4	
Fire clay refractories		
Brick, block, and tile	26.6	
Other refractories	12.9	
Total clay products other than pottery		136.3
Total Industry		217.6

between the value of the raw clay and that of the finished products. Up until 1944 the Minerals Yearbook published only the statistics on the production of "merchant" clays—that is, those which were produced for sale but not "clay burned into clay products in integrated plants at mine or pit." The 1944 Yearbook includes statistics for total production for both 1943 and 1944. The total production of domestic "merchant" raw clay (not including the much larger tonnages manufacturers produce for their own use) was valued at $15,688,434 in 1936 (Minerals Yearbook, 1937), $19,633.568 in 1940 (Minerals Yearbook, 1941), and $27,654,732 in 1943 (Minerals Yearbook, 1943), an increase of approximately 77 percent in the seven-year period from 1936 to 1943.

The value of $27,654,132 for 1943 includes only 7,380,632 tons of "merchant" clay. The Minerals Yearbook for 1944 includes statistics on both "merchant" and "captive" clays, or all clays mined for sale or use in the United States. Thus revised the total domestic production of clay in the United States in 1944 was 20,818,191 tons valued at $39,704,978. In 1944 the total·production had dropped to 17,295,328 tons valued at $36,855,275. Comparing the 1936 figures for the value of clay products manufactured (Chute, 1939) to the value of the "merchant" raw clay produced for the same year we find that the finished products were worth nearly 14 times as much as the raw clay used in their manufacture. Using this same ratio we estimate that the total value of clay products manufactured in 1943 was in excess of $387,000,000. This estimate is based on the assumption that the ratio of "merchant" clay to the total produced was the same in 1944 as in 1936, and that the value per ton of the finished products is the same. Actually the value of the finished product has increased, which would thus increase the value of the 1943 production. The exact ratios of "merchant" to "captive plus merchant" clay cannot be determined with the statistics available.

Production of brick and tile dropped from 6,211 million brick (or equivalents) in 1941 to 2,692 million in 1943. The production was even smaller in 1944. During the war inventories of bricks dropped from 889 million to 425 million (Minerals Yearbook, 1943). At the close of the war inventories of brick and tile were practically exhausted. Production decreased during the war largely because of manpower shortage, and to some extent fuel shortages. Ceiling prices set by the OPA were relatively low for brick and tile. The low prices account in part for decreased production. Since the end of the war production has increased, but most brick and tile plants were behind on orders at the beginning of 1947.

Clay industry in Kansas.—In the early days of Kansas, the brick and pottery industries were much more widely distributed over the state than they are now, although the total tonnage produced probably was not much greater. Many small communities made hand-molded bricks and fired them in scove kilns. These bricks were used locally in the construction of buildings, many of which are standing today. Small potteries were established over the state to supply local needs.

The high point of brick production in Kansas came in the period from 1900 to 1925. The highest annual production of common bricks was in 1906, when nearly 315 million were produced. The high point in the production of vitrified brick was attained in 1924, with an annual production valued at $1,237,853. The production of vitrified brick declined rapidly thereafter, because concrete replaced bricks in paving. The highest annual production of face bricks and drain and building tile was attained in 1929, when the output of face bricks was valued at $730,116 and that of drain and building tiles at $106,823.

The annual production in 1940 of all structural clay products was valued at approximately $1,500,000. If roofing tiles were included in the list, the figure for 1941 would be considerably higher. Kansas has the second largest roof-tile plant in the world. During the latter part of 1940 and most of 1941, this plant was running about 20 percent over capacity because of large government contracts. For a time this plant produced light-weight insulating refractories from central Kansas clay.

Except for the set back due to the war, clay production in Kansas has been increasing slowly since the extreme low record of 1932 and 1933. It is reasonable to expect that production will continue to increase in the future. In the opinion of experts, the timber supplies of this country were not adequate to permit continuance of the normal rate of use prior to the war years. The accelerated use of wood products during the war has made the lumber situation very critical. In the future the more durable materials, brick and concrete, may replace, wherever possible, lumber used in construction. Most of the production in Kansas is that of structural clay materials, such as brick, hollow tile, and roofing tile. These products are made mostly from red-firing shale of Pennsylvanian age that occurs in southeastern Kansas. Buff facing brick and tiles are made from a Cherokee underclay at Weir. The demand for light-colored bricks has increased in the past few years. It is probable that within the next few years production from the light-firing clays in north-central Kansas will increase progressively.

A brick and tile plant now operating near Concordia (Cloud Ceramics) is manufacturing buff face brick from a deposit of Dakota formation clay tested by the State Geological Survey (Location C-51). At present (June 1947) five beehive, down-draft periodic kilns are operating. At least one more periodic kiln and a tunnel kiln are planned for later construction. The capacity of the factory will be expanded to include the production of hollow tile. Tentative plans have also been made to include the production of refractories and pottery.

Construction is nearly completed on a brick and tile plant near Great Bend (Great Bend Brick and Tile Company). The plant is expected to be in operation some time during the summer of 1947. The Geological Survey assisted in the preliminary testing of the deposits of Dakota formation clays which they will use.

Although the bulk of clay production in Kansas has been confined to the manufacture of structural clay products, sewer and drain tile, and roofing tile, the manufacture of other types of products has not been neglected entirely. The pottery plant at Pittsburg has produced a considerable tonnage of flower pots, domestic stoneware, dinner ware, kitchen ware, and art pottery. With the exception of flower pots and stoneware, the ware is usually covered with colored glazes. These products are manufactured for the medium to low-cost trade. For several years a small pottery at Fort Scott turned out a variety of ware. Plans are being made for the expansion of the Fort Scott plant.

Since the beginning of World War II, a large pottery unit was installed at the Ludowici-Celadon Company plant at Coffeyville. Whiteware cookie jars were produced for about a year, but production has been discontinued.

A few small art potteries are operating in Kansas. In most cases the entire production is carried on by one or two people. The most recent addition to the art pottery industry in Kansas is the Dryden pottery at Ellsworth.

With the exception of the light-weight insulating refractory bricks formerly manufactured by Ludowici-Celadon at Coffeyville, and the production at one time of gas and gasoline stone refractory radiants at Wichita, the production of refractories in Kansas has been almost completely disregarded. Chemical stoneware, or porcelain, has not, to our knowledge, been produced in the State.

In 1940 a very careful analysis of the clay industry in Kansas was published (Kruger, 1940). In the light of subsequent developments the consensus seems to be that Kruger was over pessimistic. His pessimism was at that time shared by most of the producers of clay products.

CLASSIFICATION OF CLAYS

A completely satisfactory classification of clays is difficult to devise. Ries (1925, p. 174) said, "It is possible to base a classification of clays either on origin, chemical and physical properties, or uses. But since the subdivisions which can be made are not sufficiently distinct, each of these gives rise to a more or less unsatisfactory grouping." The terminology of clays is notoriously loose, and the point of view of the observer usually determines the term chosen to describe a given clay.

The following modification of the classification by Whitlach (1940, pp. 9-10) is well adapted to the purposes of this report. This classification is largely based on geologic origins, although some of the specific types are designated in terms of their uses because geologic terms have never been applied to them.

Classification of clays, based on geologic origin.

A. Residual clays
  Surface residuals formed by weathering of bedrock.
    *Primary kaolins from granite, pegmatite, etc.
    Ferruginous clays from limestones, shales, loess, or other bedrock strata; common type of surface clays.
  *Subsurface residuals, formed by ascending or descending waters of supposed meteoritic origin.
      Kaolin and bauxitic clays.
      Clays associated with iron-ore deposits.
  *Subsurface residuals, formed by ascending water of possible igneous origin.

B. Sedimentary (transported) clays.
  - By waters into lakes, swamps, or shallow seas.
    - Shale (Pennsylvanian now used in Kansas)
    - Underclay of fire-clay type (under coals in Pennsylvanian of Kansas).
    - Ball clay, plastic fire clay, siliceous fire clay (wad, sagger, and bond clay) in Dakota formation of Kansas and Cretaceous and Tertiary of west Tennessee and Kentucky.
    - Kaolin. Occurs in thin beds in the Dakota formation of Kansas.
    - Bentonite (transported in part by wind). In Cretaceous and Tertiary of Kansas.
    - Alluvial clay, along flood plains of Pleistocene and present streams (widespread in Kansas).
    - Colluvial clay. Deposits formed by wash from any other type of deposit.
  - By wind.
    - Loess (transported in part by water). Many occurrences in Kansas. Often covers older rocks with thin mantle.
    - Bentonite (transported in part by water).
  - By ice.
    - Glacial clay (northeast Kansas).

*Not known to occur in Kansas.

Mineralogic Properties of Clay

For many years clay was thought to be an amorphous substance —a mass of minute but formless particles. This was a natural error, inasmuch as most of the particles in the majority of clays are formless under the highest magnification attainable with an optical microscope. In recent years, with the aid of the petrographic microscope (Grim, 1941), the X-ray, differential thermal analysis apparatus (Grim and Rowland, 1942; Pask and Davies, 1943; Berkelhamer, 1944; Grim, 1944; Spiel, 1944; Spiel, Berkelhamer, Pask, and Davies, 1945), and finally the electron microscope (Humbert, 1942; Shaw, 1942), the fact has been well established that clays are aggregates of very minute crystals of one or more of a few minerals known as the clay minerals (Grim and Bray, 1936; Grim, 1942). Of these clay minerals the kaolinite, illite, and montmorillonite groups are the most important. The names kaolinite and montmorillonite are taken from the most important clay mineral member of the groups. At present illite is a group name only, specific names not having been established for members of this group (Grim, Bray, and Bradley, 1937).

Most clays, in the natural state, are mixtures of the clay minerals. The outstanding ceramic properties of a clay are determined by the proportion of the various clay minerals present. The relation between mineral composition and physical properties of clay is briefly but very comprehensively discussed by Grim (1939) in an article in the Journal of the American Ceramic Society. To quote from the abstract of this article (p. 141):

> The clay minerals occur in flake-shaped particles, possess base-exchange capacity, and exist in or are reducible to extremely small grain sizes on working with water. Different clay minerals possess these properties in varying degrees.
>
> The clay mineral component is the chief factor determining the properties of a clay. In general, plasticity and bond strength caused by the clay minerals decrease in the following order: montmorillonite, illite, and kaolinite. In many clays, the plasticity and bond strength mainly result from the presence of montmorillonite minerals or some members of the illite group, although these constituents may compose only minor amounts of the clay. . . . .The green properties of clays are also related to the character of the exchangeable bases carried by the clay minerals. . . . . The properties of clays are related further to the effective size-grade distribution developed in use which frequently differs from the size-grade obtained by mechanical analysis.

The clay mineral component chiefly determines not only the plasticity and bond strength of the clay in the green or unfired state, but also its workability and drying behavior. Fired properties of the clay, including color, shrinkage, and temperature of fusion are also determined to a large extent by the proportion of various clay minerals present. For example, the familiar English china clay and the kaolins of Georgia, Florida, and North Carolina are composed almost entirely of the mineral kaolinite in comparatively large particle sizes. The red-firing shales of Pennsylvanian age from which most of Kansas brick and tile are now manufactured are composed dominantly of the illite clay minerals with but small amounts of kaolinite. The extremely plastic clay, bentonite, which is used as a drilling mud, suspending agent, or decolorizer, is composed largely of montmorillonite.

The important clay minerals are kaolinite, montmorillonite, and the illite group. These occur in flake-shaped particles, which if sufficiently magnified would look somewhat like pulverized mica. The kaolinite crystals are hexagonal plates with clearly defined edges. The other clay minerals occur in plates of less definite shape. In general, kaolinite particles are the largest of the three and are thicker, being made up of several layers of unit crystals firmly bonded together. The montmorillonite and illite crystals are smaller and tend to break down into even smaller aggregates when water is added to the clay. This is due to the fact that water enters between the structural units and separates the particles into smaller flakes. Illites vary in their capacity to break into smaller units along cleavage surfaces when water is added to the clay.

In general, however, the particle size of illite clay is intermediate between that of kaolinite and montmorillonite. In any clay the overall dimension of the majority of the particles ranges from 2.0 microns (0.002 mm) to 0.1 micron (0.0001 mm), although both larger and smaller particles may be present (Humbert, 1942).

The surface area per unit volume in a clay increases as the particle size decreases. Clays which break up into very thin flakes have an especially large total area of surface in proportion to the volume. The capacity of a clay to adsorb water increases in proportion to the increase of surface area per unit volume. Inasmuch as the viscosity of the water film and its lubricating effect largely account for the plasticity of clays, it is evident that finely divided clay composed of thin flakes would be more plastic than coarser clays made up of relatively thicker flakes. The ability of the clay to adsorb water not only increases the plasticity, but also increases the shrinkage of the clay on drying because the water takes up space by holding the clay particles apart. The water of plasticity and the drying shrinkage of a clay are therefore directly related to the particle size and clay mineral composition (Smothers and Herald, 1944; Grim and Cuthbert, 1945).

The illite clay minerals contain iron, potassium, and magnesium as an integral constituent of the crystal lattice. These constituents have a marked effect on the fired properties of clays containing illite. The iron oxidizes to hematite on firing and produces a red color. All three elements reduce the fusion point of the clay. In general, therefore, illite clays are not refractory and vitrify at relatively low temperatures. Shrinkage on firing is also high in comparison with kaolinite clay, and illite clays tend to bloat at vitrification.

Owing to the high base exchange capacity of montmorillonite, sodium, potassium, magnesium, and calcium ions are likely to be taken up by montmorillonite clays, increasing the fusibility and firing shrinkage. Both drying and firing shrinkage of montmorillonite clays is usually so great that a sound test brick cannot be produced from them. The base exchange capacity of illite may produce similar results in illite clays. However, in both illite and montmorillonite, silica ions may be replaced by aluminum ions. This replacement would tend to make the clay more refractory and to have a lower firing shrinkage.

The base exchange capacity of kaolinite is so slight that the kaolinitic clays are almost completely stable in the presence of basic ions.

Accessory minerals commonly found in clays also have important effects on their properties. The most abundant accessory mineral is quartz, which may be present in particle sizes ranging from sand to colloidal dimensions. Even very finely divided quartz does not become plastic when water is added to it, although colloidal silica may produce stickiness and greatly increase the dry bonding strength of the clay. In general, the presence of quartz in a clay lowers the plasticity and drying shrinkage, which in many cases is desirable. Quartz is refractory, and therefore does not in itself lower the fusion point of a clay, although it has important effects on the fired properties. Firing shrinkage is decreased and porosity increased. Futhermore, quartz is slowly converted to tridymite above 1,598°F., and to cristobalite above 2,678°F. With these conversions the volume of the silica mineral increases. This increase in volume may reduce the fired strength of the clay body, and if a glaze is applied to it, produces crazing or shivering.

Iron oxides in the form of hematite or limonite are present in all clays. If present in amounts above 2 or 3 percent the clay will fire to a pink or red color. Smaller percentages of iron compounds produce cream and buff colors. Iron oxide combines with clay to form glassy silicates at relatively low temperatures, thus decreasing the refractory quality of the clay. Pyrite or marcasite, the sulfide of iron, is a mineral commonly found in clay either in the finely divided state or in the form of fairly large nodules or crystals. Usually it oxidizes to hematite on firing, but in an atmosphere poor in oxygen it may be reduced to ferrous iron, or combine to form readily fusible silicates.

Calcite and selenite are extremely detrimental to a clay if they occur in large amounts. If the calcite or lime occurs in particles large enough to remain on a 30-mesh screen, popping will result when the clug is fired, for the calcite is converted to quicklime on firing and subsequently slakes when exposed to the air, thus producing an expansion which either breaks out a small portion of the fired piece or causes it to disintegrate entirely. Selenite, or gypsum, does not produce this effect, but it causes scumming, and lowers the fusion point of the clay. Calcareous clays have a very low fusion point and an extremely short vitrification range. However, clays containing less than 10 percent lime usually fire to a buff color although the iron oxide content may be high enough to produce a red color in a noncalcareous clay.

Other accessory minerals commonly present in clays in small amounts are zircon, tourmaline, rutile, and ilmenite.

CHEMICAL PROPERTIES OF CLAY

The ultimate chemical analysis is the most accurate and the most commonly employed method of determining the constituents in a clay. The chemical composition is expressed as oxides of the elements. Chemically combined water and other volatile constituents are usually reported as loss on ignition.

Pure kaolinite is given the formula $Al_2O_3.2SiO_2.2H_2O$. An ultimate chemical analysis of this clay mineral would be reported as follows: silica (SiO_2), 46.5 percent; alumina (Al_2O_3), 39.5 percent; loss on ignition (H_2O in this case), 14.0 percent. The chemical formula for pure montmorillonite is $Al_2O_3.4SiO_2.xH_2O$. Owing to base exchange capacity, magnesium, calcium, potassium, or sodium usually occurs in the molecule. A chemical analysis of a purified, but not chemically pure, montmorillonite follows: silica (SiO_2), 64.60 percent; alumina (Al_2O_3), 20.80 percent; ferric oxide (Fe_2O_3), 3.05 percent; ferrous oxide, (FeO), 0.46 percent; magnesium oxide (MgO), 2.30 percent; calcium oxide (CaO), 0.53 percent; sodium oxide (Na_2O), 2.60 percent; potassium oxide (K_2O), 0.40 percent; loss on ignition (H_2O), 4.74 percent (Grim and Bradley, 1940).

Illite does not have a definite chemical composition inasmuch as it is a group of clay minerals. The general formula is written $(\mathrm{OH})_4\mathrm{Ky}(\mathrm{Al}_4.\mathrm{Fe}_4.\mathrm{Mg}_4.\mathrm{Mg}_6)$ $(\mathrm{Si}_8\mathrm{y}.\mathrm{Aly})\mathrm{O}_{20}$. An ultimate chemical analysis of a purified illite follows: SiO_2, 51.22 percent: Al_2O_3, 25.91 percent; Fe_2O_3, 4.59 percent; FeO, 1.70 percent; MgO, 2.84 percent; CaO, 0.16 percent; Na_2O, 0.17 percent; K_2O, 6.09 percent; loss on ignition, 7.49 percent (Grim and Bradley, 1940).

Silica.—Silica occurs in clay as hydrous aluminum silicate in the clay minerals, as uncombined silica in the form of quartz or colloidal silica, and in small amounts in other silicates such as mica. The influence of free silica upon the texture, bonding power, plasticity, refractoriness, and other physical properties of the clay is discussed at some length under the mineralogic properties of clay.

Alumina.—Most of the alumina in the clays of the Dakota formation occurs in the clay mineral kaolinite. Both illite and montmorillonite, however, are aluminum silicates containing from 20 to 25 percent alumina, and are common constituents of most clays. Alumina is the most refractory substance in clay. In general the refractoriness of a clay increases in proportion to the increase of the alumina-silica ratio, although this is modified greatly by the amount of fluxing materials which may be present.

Iron Oxide.—The iron oxide of clays is usually present in the form of hematite or limonite, but may occur as siderite or pyrite. In the case of the illite clay minerals, iron is an integral constituent of the molecule, but appears in the fired clay either as the ferric or ferrous oxide or recombines as a silicate. The percentage of iron oxide in a clay usually determines or limits its range of usefulness. With the exception of illite, pure clay fires to a white color. White-firing montmorillonite, however, is extremely rare. With increasing percentages of iron oxide the colors vary through ivory, cream, buff, pink, and red. Iron is also an active flux in clays, particularly if the clay is fired in a reducing atmosphere. The ferrous silicates have a much lower temperature of fusion than the ferric compounds.

Calcium oxide.—Most of the lime in clay is present in the form of calcite or aragonite (calcium carbonate) and gypsum (calcium sulfate). Clays containing more than 5 percent calcium oxide usually are considered not usable, although clay containing as much as 10 percent finely divided calcium carbonate does have limited uses, as in slip glazes. Lime in considerable quantities will prevent the development of the red color due to iron, but a calcareous clay is difficult to fire. It remains open, or porous, to a point close to the vitrification temperature. The glassy calcium silicate phase occurs abruptly, and unless the kiln is controlled very carefully the ware will melt or bloat.

Magnesium oxide.—The source of magnesium oxide in clays is the carbonate, the sulfate and to some extent silicates, including mica and the clay minerals illite and montmorillonite. Magnesium oxide has a fluxing action similar to lime, and when it is present in the clay in the form of the soluble sulfate (epsom salts) it produces an objectionable white scum or film on the fired ware.

Alkalies.—The alkalies commonly present in clays are potash (K_2O) and soda (Na_2O). In residual clays the alkalies may be present in the form of feldspar. The most common source in sedimentary clays is the illite group of clay minerals in which potassium is a constituent of the crystal lattice. The alkalies are not particularly detrimental in clays used in the manufacture of brick, tile, or pottery, but even very small amounts act as powerful fluxes even at low temperatures, and are consequently very detrimental to refractory clays.

Sulfur oxides.—Sulfur may occur in a clay in the form of organic matter, gypsum, pyrite, or soluble sulfates such as epsom salts. Sulfur dioxide and trioxide are produced when the clay is fired, and if these gases are not completely expelled before vitrification of the clay seals the gases in, their expansion will produce a vesicular structure and bloating of the clay.

Titanium dioxide.—Titania usually occurs in clay in the form of rutile and ilmenite. Although chemical analyses show titanium oxide to be present in amounts commonly ranging from 1 to 2 percent, its presence is seldom detrimental. In a vitrified light-firing clay it may produce a bluish tint, and in softer-fired well-oxidized ware a yellowish tint. There is some evidence to support the conclusion that titanium changes the coloring effect of iron away from red toward yellow, buff, or brown, depending on the quantity and proportions of titanium and iron. To an extent titania acts as a flux, but it is not nearly so active as iron oxide.

Water.—Water is mixed with clay to form a plastic mass which can be shaped into desired forms. This tempering water must be carefully expelled from the clay before the actual firing of the clay begins; otherwise the vapor will cause the ware to burst. Any inorganic substances which the tempering water contains become a part of the clay after forming. In most cases such substances are present in amounts too small to be of importance, but in some cases they affect the quality of the ware. Soluble sulfates, for example, will produce a white efflorescence or scum on the fired ware. Iron compounds may also be present in amounts sufficient to discolor whiteware.

The water which is held in chemical combination in the clay minerals is driven off when the ware is fired in the kiln. This dehydration begins at about 700°F. The bulk of the water has been expelled at approximately 930°F., but the last traces of water are not driven off until a temperature of 1,472°F. has been reached. The dehydration or "water smoking" period must proceed rather slowly in firing to prevent disruption due to the pressure of the vapor.

Phosphorous pentoxide.—If present in clays phosphorous usually occurs in very small amounts and has no detrimental effects. Ries (1927) states that phosphorous is probably present either as calcium phosphate or as the phosphate of iron, vivianite. The addition of substantial amounts of a phosphate to clay will improve the color of light-colored ware, and increase the fusibility.

Vanadium pentoxide.—Traces of vanadium compounds are of common occurrence in clays, although the quantity, expressed as the pentoxide, seldom exceeds a fraction of 1 percent. Vanadium can be a source of no small amount of trouble to the manufacturer of light-colored products such as facing brick and terra cotta in that it will produce a green efflorescence when present in amounts as small as 0.001 percent V_2O_5. Various remedies have been suggested for the solution of this problem. Firing the clay to a higher temperature will solve the problem by producing insoluble silicates of vanadium. Firing under reducing rather than oxidizing conditions also has been suggested (Seger, 1902; Ries, 1927).

CERAMIC AND OTHER PHYSICAL PROPERTIES

Later in the report we describe in detail the methods used in our laboratory to obtain the test data on ceramic and other physical properties. On the pages immediately following are given definitions, interpretations, and general descriptions of these properties.

The green (unfired) properties of a clay which largely determine its economic value are plasticity, strength, shrinkage, and bonding power. The fired properties are color, shrinkage, and refractoriness. Structure of the green clay, rate of slaking, and the specific gravity of both the green and fired clay are important but not critically significant.

Plasticity.—Plasticity is the property of a clay which permits it to change form when pressure is applied to it, and to retain that form when the pressure is released. The amount of pressure required and the resultant deformation vary with the plasticity. In practice, clay workers include the properties correctly ascribed to workability in their estimation of plasticity. The extent to which a plastic mass may be deformed without rupture, and smoothness or stickiness are properties rightly described under workability (Graham and Sullivan, 1939).

The plasticity of clay depends on the shape, size, and kind of particles in the clay. In general, the smaller the particle size the greater the plasticity. The clay minerals, however, vary greatly in plasticity, regardless of size, and materials such as quartz are almost entirely lacking in plasticity. The water films adsorbed on the flake-shaped particles probably account for much of the plasticity of clays. The water film acts as both a lubricant and a bond, permitting the particles to slide over one another without breaking apart. Organic matter, commonly present in colloidal form, also tends to increase plasticity.

Water of plasticity, or the amount of water which must be added to a dry clay to make it plastic, varies with the plasticity. In general, the lean or silty clays have a lower water of plasticity than the very fine-grained plastic clays (Pl. 2). Drying shrinkage also increases with plasticity. Extremely plastic clays are likely to warp or crack when dried or fired due to high shrinkage. The plasticity of a clay largely determines its range of usefulness. Whitlach (1940, p. 19) states:

> Clays used for structural wares of complicated shape must have greater plasticity than those used for simpler shapes, as brick, but extremely plastic clay, like ball clay, is not desirable for such wares, owing to its high shrinkage, although high plasticity is desirable for the normal uses of ball clay. Hence, plasticity is evaluated largely on the basis of the proposed use of the clay.

In describing the occurrence of specific samples we use the terms very plastic, plastic, slightly plastic, slightly silty, silty, etc. in this report. Ordinarily the term "plastic" is reserved for the laboratory and work shop, but with a slight degree of care, and the application of a little saliva it is possible in the field to judge, with fair accuracy, the plasticity of a clay. An extremely smooth slick clay is usually highly plastic, whereas a gritty, harsh-feeling clay is obviously silty, and is usually but slightly plastic.

Strength.—The green (unfired) strength of a clay must be sufficient to permit handling during the drying stages and setting the ware in the kiln without undue breakage. The transverse strength test is the accepted method of determining both the green and the fired strength of a clay. The method of conducting this test is described under laboratory methods.

The more plastic clays and those having a higher percentage of water of plasticity are, in general, stronger than silty clays. Nearly pure, relatively coarse-grained kaolin, however, has a high transverse strength and water of plasticity, but is only weakly plastic. Of the Kansas clays tested those having the greatest transverse strength were the ball clays and the illitic Kiowa shale; those having the least transverse strength were the extremely silty fire clays and the nearly pure kaolins.

Bonding power and slaking.—The ability of a clay to bind together inert nonplastic materials is its bonding power. Ball clays are commonly used in whiteware and porcelain bodies because of their ability to bind together the silica, feldspar, and other nonplastic ingredients. Plastic fire clays are used to hold together the grains of fired clay (grog), or other slightly plastic materials such as flint clay. The transverse strength of a clay is directly related to its bonding power. The time required for a 1-inch cube of clay to slake in water is also an indication of the strength of the bond between the individual clay particles.

Refractoriness.—A refractory clay is one which is capable of withstanding high temperatures without deforming. The Committee on Geological Surveys of the American Ceramic Society recommends that the term "refractory" be restricted to clays having a P. C. E. of cone 27 (2,921°F.) or higher, and that all clays having P. C. E. of not less than cone 19 (2,768° F.) be called "fire clays." As ordinarily used, however, the term refractory is applied to any clay having a P. C. E. of cone 19 or higher. Pure kaolinite has a P. C. E. or deformation temperature of about cone 35 (3,245°F.). On the other extreme clays which fuse to a glass at 2,000°F. are not uncommon.

Clays do not have a definite melting point. Pure kaolinite, although in the natural state a definite chemical compound, changes into a physical mixture of mullite and quartz at high temperatures. The resulting compound melts over several degrees of temperature, and is extremely viscous when completely fused. Most clays are mixtures of compounds having various temperatures of fusion. When heat is applied to such clays, those compounds having the lowest fusion point will be the first to melt and form a glassy phase within the interstices of the solid or unfused portion. This glassy phase tends to flux the more refractory materials at temperatures below their normal fusion point due to the formation of complex silicates. The common fluxing materials in clay are iron oxide, calcium and magnesium oxide, and the alkalies. Although quartz is nearly as refractory as pure kaolinite, certain mixtures of the two materials melt at much lower temperatures than either will alone. In a sense, therefore, the quartz in a clay acts as a flux.

The indefinite or prolonged fusion of clay is very advantageous. In the manufacture of many types of ware it is necessary that the clay be vitrified. This means that almost all the pores or open spaces have been filled by partial fusion and shrinkage of the entire mass. Owing to the solid phase contained within the glassy matrix and to the high viscosity of the glass, the ware holds its shape although so nearly fused. Fine-grained clays containing a considerable amount of kaolinite—for example, ball clay and plastic fire clay—may be fired several cones above the temperature of initial vitrification. Such clays are said to have a long vitrification range. Usually a clay must be refractory to have a long vitrification range, although particle size and the type of fluxes present in the clay have an important bearing on this property. Calcareous clays have a particularly short vitrification range, changing from a relatively porous material to formless glass with a slight increase in temperature.

Shrinkage.—Clay is shaped or formed in the plastic condition. On drying, the plastic clay shrinkage occurs, the amount of shrinkage being roughly proportional to the amount of tempering water used—the water of plasticity. When the dried clay is heated to a temperature ranging from 1,100°F. to 1,800°F. shrinkage again occurs, and the clay continues to shrink with the increase of temperature until vitrification is reached. Highly siliceous clays are an exception to this rule owing to the increase of volume when quartz is converted to tridymite and cristobalite at high temperatures. Both the drying and firing shrinkage of a clay can be greatly reduced by calcining a portion of the clay, which is crushed, sized, and mixed with the plastic clay. The crushed calcined clay is known as grog in the clay industry. The addition of grog is a common practice in the manufacture of firebricks. Usually the grog is composed of a clay different from the bond.

Kaolin shrinks very little either in drying or firing. Kaolinitic clays, such as ball clay and plastic fire clay, have a comparatively high shrinkage on drying and a moderate shrinkage on firing. Illite shales, on the contrary, have a moderate drying shrinkage and a comparatively high firing shrinkage.

Porosity and absorption.—About porosity and absorption Whitlach (1940, p. 23) states:

> The porosity or pore space in a clay is the unoccupied spaces between clay grains. Its volume is dependent on the ratio of sizes, shape, and arrangement of the clay particles. The pore spaces between the particles form tubes of capillary size through which water moves by capillary action; consequently, the more porous a clay, the more readily it tempers to a plastic mass and more readily dries. Plastic fine-grained clays have very small pore spaces and do not dry readily, but sandy clays with high porosity dry quickly.
>
> The porosity of a clay gradually decreases during firing and approaches zero at vitrification. Porosity of a fired clay is obviously related to its ability to absorb water. Such absorption is measured by the quantity of water that can be taken up by a unit of the fired body. Low absorption is desirable in products exposed to weathering or discoloring agents, and the degree of porosity has a bearing on the strength of a fired body and its resistance to shock, abrasion, or erosion.

Color.—The color of raw clay is usually of no importance unless it is to be used as a filler. There is often very little relationship between the raw and the fired color of a clay. Black kaolinitic clays usually fire to a white or cream color, whereas black illitic clays fire to a red color. Clays having tints of yellow, green, or blue are also likely to fire to a red color. The red color of hematite in a raw clay is changed very little by firing, however. The fired colors of clay are due, for the most part, to iron compounds.

Titanium may contribute a yellow or blue tint, but its effect is not especially important.

Fired color is one of the most important properties of clay because industry and the consumers demand certain colors in specific types of ware. Clays used in whiteware and porcelain must fire to white or ivory. Earthenware pottery and stoneware are usually manufactured from light-firing clays, although a red-firing clay may in some cases produce a superior product. Firebrick and other refractories are always manufactured from white to buff-firing clays, for the excellent reason that red-firing clays are seldom refractory. Even if they were sufficiently refractory and excellently suited to certain uses no consumer could be induced to buy a product made from them. Face brick and other decorative structural wares are made from light-firing clays for specific uses. Other types of structural ware such as building tile, common bricks, and dark face bricks are quantitatively very important products which are manufactured from red-firing clays or shales.

Specific gravity.—In the ceramic tests both bulk and apparent specific gravity of the fired clay are determined. The bulk specific gravity is the weight per unit of over-all volume expressed in terms of the density of water. The apparent specific gravity represents the solid materials plus sealed pores. The volume of the open pores is calculated from the percentage of water which the fired clay will absorb, and this volume subtracted from the bulk volume gives the volume of the solids plus the sealed pores which will not absorb water. Inasmuch as the sealed pore space is relatively small, especially in a permeable body, the apparent specific gravity closely approximates the true specific gravity of the clay. In tests carried out on Kansas clays, the apparent specific gravity decreased as vitrification progressed, indicating chiefly that the greater percentage of the pore space had become impermeable to water as the clay became increasingly glassy with elevation of temperature. The bulk specific gravity, on the other hand, increases with temperature of firing owing to the shrinkage of pore spaces, or filling in with the glassy phase. Near vitrification the bulk specific gravity and apparent specific gravity approach the same value.

The bulk specific gravity is particularly useful to the manufacturer in estimating the variation in weight of a product of standard size made from various types of clay.

CLAYS OF THE DAKOTA FORMATION IN KANSAS

Geology of the Area

The clay beds of the Dakota formation receive primary consideration in this report, but the beds of the underlying Kiowa shale and the overlying Graneros shale formation are discussed in some detail. Permian shales, the Cheyenne sandstone formation, and the Greenhorn limestone formation are incidentally mentioned. The stratigraphic relationships of the various beds discussed are shown below.

- Cretaceous System
  - Gulfian Series
    - Greenhorn limestone formation
    - Graneros shale formation
    - Dakota formation
  - Comanchean Series
    - Kiowa shale formation
    - Cheyenne sandstone formation
- Permian System
  - Wolfcampian to Guadalupian Series

Typically the area of outcrop of the Dakota formation and related beds is hilly and rocky, but the topography is modified in many places by alluvial or loess deposits. The outcrop area of the Dakota formation covered by this report is shown in Figure 1.

PHYSIOGRAPHY AND TOPOGRAPHY

The belt of clay outcrop is in the Plains Border section of the Great Plains physiographic province. It is characterized by a maturely dissected, moderately fine-textured topography. The area is crossed by broad valleys that have reached a mature stage of development. The valleys are flanked by high-level terraces, and the upland regions veneered with thin deposits of Pleistocene silt and clay.

The Dakota formation is made up of beds of materials differing markedly in their ability to resist erosion. All of the clay disintegrates rapidly in water and is readily transported in suspension. The sandstone and silt beds, on the other hand, commonly become case-hardened and resist erosion, although some portions of the beds may disintegrate to a mass of loose sand or silt on being exposed to the weather. The sand and silt, however, is transported much less readily than the clay because the larger particle size does not permit these materials to remain suspended in water unless the current velocity is relatively great.

For these reasons the topography of the outcrop area of the Dakota formation is distinctive, consisting to a large extent of steep-sided hills of irregular shape, capped by resistant sandstone which weathers to a dark brown. Lower lenses or layers of sandstone produce irregular benches or even lumps on the hillsides. (Pl. 4B).

The topography of both the Kiowa and Graneros shale outcrop areas is influenced by the same conditions although other factors may be of equal or greater importance. In areas where the top of the Dakota formation, the Graneros shale, and the overlying Greenhorn limestone are exposed, the resistant sandstone or silt at the top of the Dakota formation (underlain by soft clay) and the resistant limestone in the lower part of the Greenhorn (underlain by soft shale) produce benched or flat-topped hills, with steep slopes (Pls. 4C and 5A).

In many places in the Dakota outcrop area, the outline of the hills is softened by a surface covering of loess, a terrace and glacial till deposit of Pleistocene age, giving small areas a gently rolling or even plains topography. Several levels of terrace deposits are conspicuously present along the major streams and some of their tributaries, and old stream channels, remnants of an earlier drainage pattern, cross the present divides. Probably the most well defined of these old channels is the Wilson high-level valley which crosses the Smoky Hill-Saline River divide a few miles northeast of Wilson, in Ellsworth, Lincoln, and Russell Counties (Frye, Leonard, and Hibbard, 1943). Glacial outwash and till in Washington County and high terrace deposits in the other counties cover a relatively large portion of the surface in the clay belt, and clay exposures are found only where streams have succeeded in cutting through the younger beds into the bedrock.

Five major streams and their tributaries, the Little Blue, Republican, Solomon, Saline, and Smoky Hill Rivers drain the central and north-central region, and two streams, the Arkansas and Pawnee Rivers, drain the southwest area.

In the clay belt the local as well as the regional relief is considerable, ranging from an altitude of about 1,200 feet above sea level in Ottawa County to approximately 2,400 feet in Ford County, a total regional relief of 1,200 feet. The greatest local relief probably is in Ellsworth and Saline Counties where the base of the Kiowa shale is found at an altitude slightly under 1,300 feet above sea level, and the top of the Graneros shale at a point 30 miles to the west-southwest is 500 feet higher, or nearly 1,800 feet above sea level. In the Terra Cotta area west of Brookville, Kansas, the altitude varies from 1,300 to more than 1,700 feet in a distance of 5 miles. Hills ranging from 200 to 300 feet in height from base to top are common throughout the outcrop area of the Dakota formation.

STRATIGRAPHY

The major part of this report is concerned with the occurrence and ceramic properties of clay deposits in the pre-Greenhorn Cretaceous beds of north-central, central, and southwestern Kansas. The stratigraphic information acquired in the field and laboratory during the investigation of the clay deposits resulted in a reclassification of these beds, which has been described in detail by Plummer and Romary (1942). In this paper the new classification is summarized as follows (p. 315):

> The oldest Cretaceous rocks known in Kansas, which are of continental origin, are classed as the Cheyenne sandstone. Dark marine shale and sandstone above the Cheyenne sandstone are assigned to the Kiowa shale. These two stratigraphic units, named from Kiowa County, Kansas, have been recognized by workers for many years and can be correlated with beds in the north-central Kansas region.
>
> Nonmarine clay and sandstone deposits that overlie the Kiowa shale are here designated as the Dakota formation [Fig. 2, this bulletin]. The Dakota is limited upward by the base of the Graneros shale. The formation is here subdivided into two members: The Terra Cotta clay member at the bottom and the Janssen clay member at the top [Pls. 3, 4C, and 5A]. The marine shale above the Dakota formation and below the Greenhorn limestone is classified as the Graneros shale [Fig. 2; Pl. 3C].
>
> The continental or near-shore Cheyenne sandstone is thought to represent deposits made near the strand line of the northward-advancing Cretaceous sea. The Kiowa shale was deposited in a relatively shallow sea. The Dakota formation comprises clay and sand deposited on flats not far above sea level. Deposition of the Dakota beds was terminated by a re-advance of

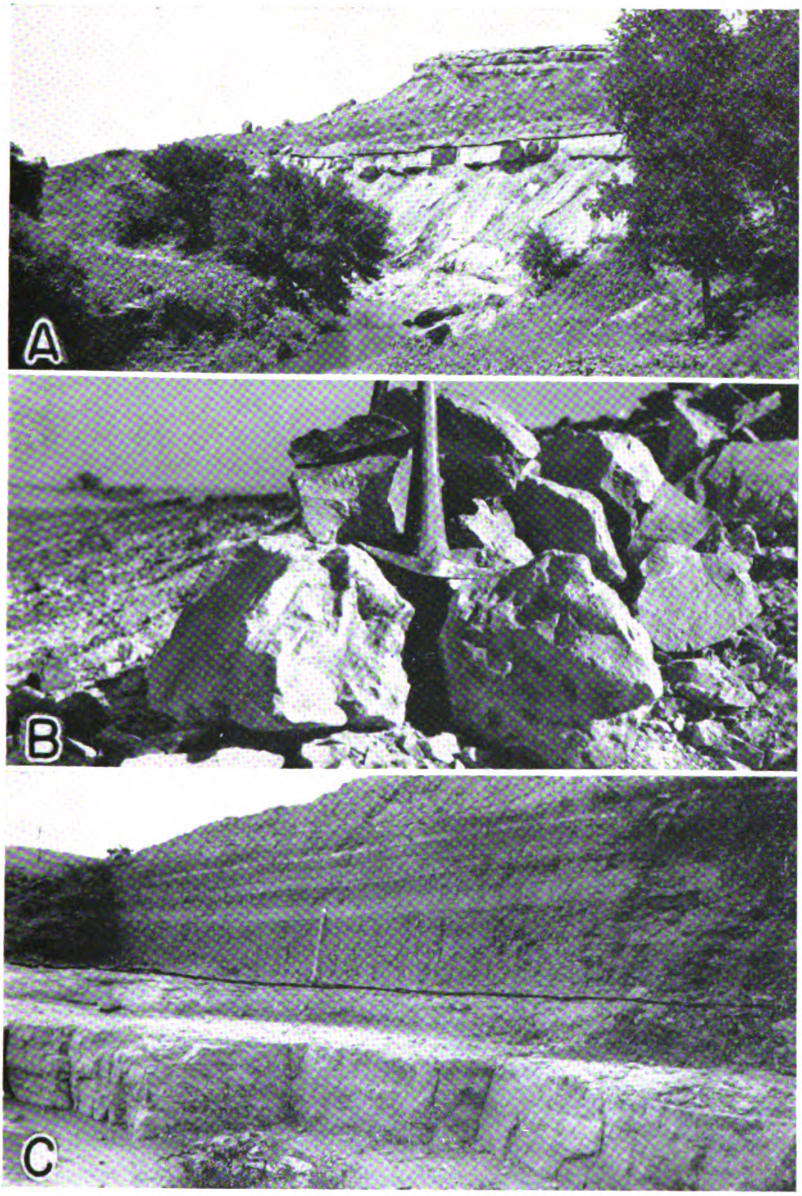


Plate 3.—*A*, Outcrop of Janssen clay member of the Dakota formation. Shows resistant upper siltstone (black line indicates top), underlain by massive clay. Graneros shale and Tertiary beds crop out on the slope above the siltstone. Cemented Tertiary conglomerate caps the hill. *B*, Freshly excavated massive clay from the Janssen clay member. Shows conchoidal fracture (Location El-54). *C*, Contact of the upper Janssen siltstone and Graneros shale. Dark line indicates contact.

the sea, and in this sea the marine shale and sandstone of the Graneros formation accumulated.

The clay and shale occurring in the Cretaceous beds lying below the Greenhorn limestone differ greatly in ceramic properties and economic importance due to factors which are also involved in geologic origins and stratigraphic classification of the beds.

Cheyenne Sandstone

The Cheyenne sandstone, which is exposed only in south-central Kansas consists chiefly of sandstone and silt, but also contains beds of light-firing clay that are quantitatively unimportant but that are similar to those of the Dakota formation.

Kiowa Shale

The dark-colored marine shale of the Kiowa formation is a very poor ceramic material; it is composed dominantly of the illite clay minerals but contains some montmorillonite. This shale is extremely plastic, is difficult to dry, and fires without cracking or warping, but the fired colors are unpleasant browns or reddish-browns.

Dakota Formation

The Dakota formation, which is restricted to include only the continental and littoral beds that occur above the Kiowa shale and below the Graneros shale, contains ceramically valuable clays in great abundance. These clays differ mineralogically from the majority of the clays that occur in Kansas in that they are composed dominantly of the clay mineral kaolinite. Where they are relatively free from iron compounds they fire to colors ranging from white to buff, and they are refractory.

Numerous sandstone layers and lentils are found in the Dakota formation, and although sandstone is locally very prominent, clay is quantitatively the most important type of sedimentary material in the formation. The Dakota formation is divided into two parts, the lower of which is the Terra Cotta clay member and the upper, the Janssen clay member (Fig. 2). The Terra Cotta clay member includes massive clay, silt, and sandstone, comprising approxi-

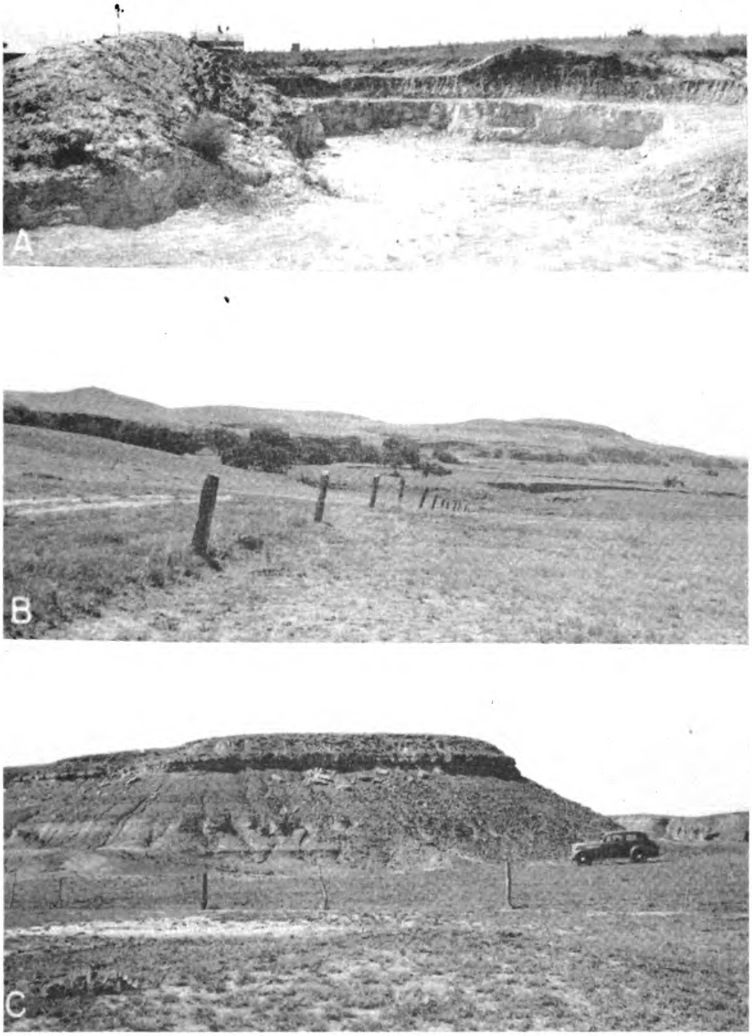


Plate 4.—*A*, Pit from which Dakota formation clay was removed for the manufacture of buff facing brick in a Nebraska plant. Beds 1 and 4 of Washington County location W-1 are exposed. *B*, Topography typical of the Dakota outcrop area; Hell Creek Valley in Lincoln and Russell Counties from near location L-39. *C*, Outcrop of the Janssen clay member showing typical flat-top hills resulting from resistant upper siltstone, Ellsworth County, location El-73.

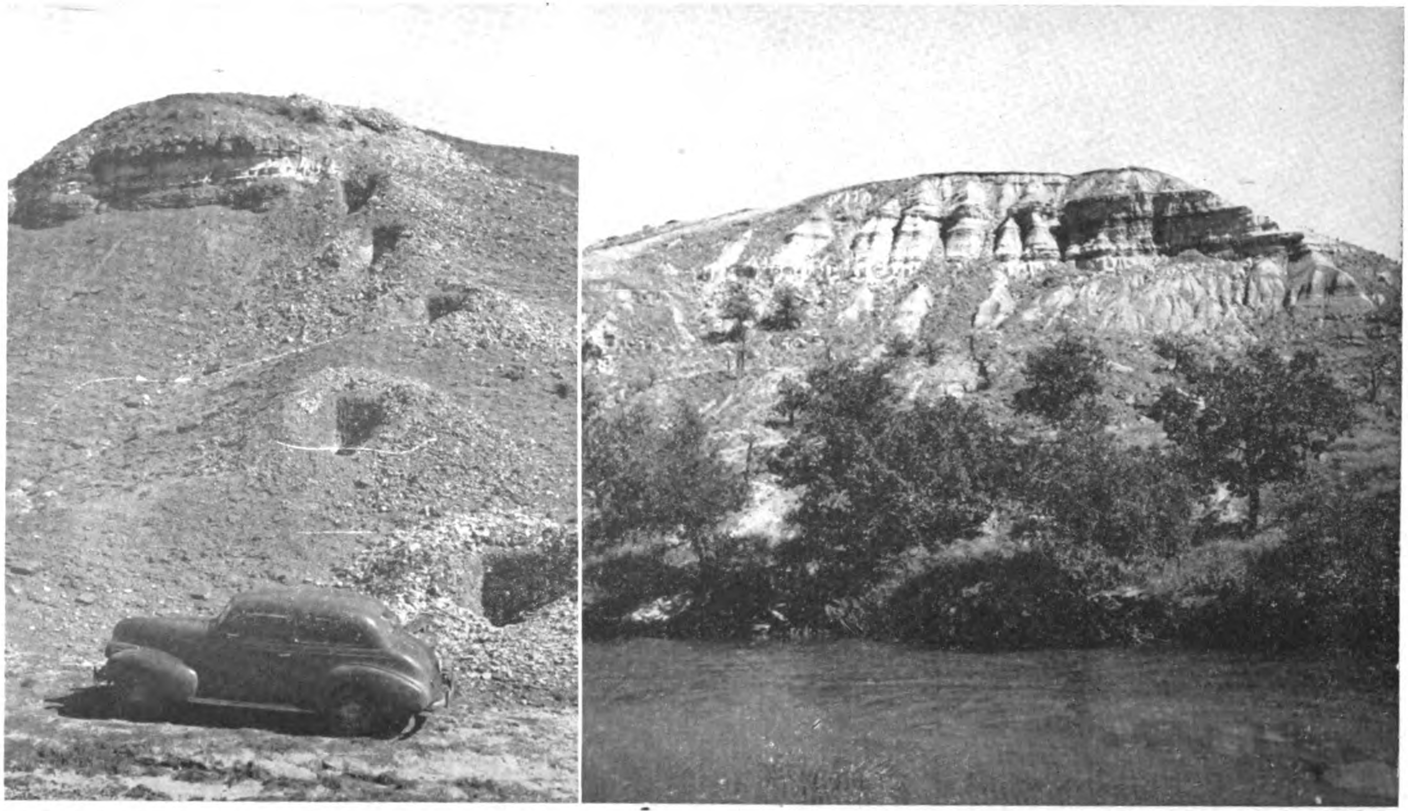


Plate 5.—*A*, Typical exposure of Janssen clay member showing resistant upper siltstone, and method of excavating pits for the purpose of obtaining samples across the entire face of the exposure; Ellsworth County, location El-82. *B*, Exposure of Dakota formation clay and Kiowa shale at location El-22, Ellsworth County. Top of cliff is 190 feet above water.

mately the lower two-thirds of the Dakota formation. The most conspicuous lithological feature of the Terra Cotta member is the widespread distribution of gray-and-red-mottled massive clay, although beds of gray clay lacking the irregular hematitic red stain are abundant. The Janssen member includes beds of lignite, gray to dark-gray massive clay, silt, and some shale above the Terra Cotta member and below the Graneros shale (Pls. 3A, 3C, 4C, and 5A). The numerous and irregularly distributed sandstone bodies which occur in the Dakota formation, together with lateral variations in the quality and thickness of the clay beds, introduce considerable complexity into quantitative estimates of the clay reserves. We have estimated, however, that clay comprises approximately three-fourths of the total thickness of the Dakota formation, and that from one-fourth to one-third of the clay is white to buff-firing, although nearly half of the samples collected were buff or lighter in color when fired (Table 26). In the area of outcrop the Dakota formation ranges from 180 to 300 feet in thickness.

Graneros Shale

Dark marine shale and rusty brown to light-colored marine sandstones comprise the Graneros shale formation, which lies above the Dakota formation and underlies the Greenhorn limestone. The dark shale is similar in appearance and ceramic properties to the Kiowa shale. The Graneros shale differs, however, in that this shale contains thin persistent beds of bentonite, whereas none has been found in the Kiowa shale in the central area, although a bed of bentonite or bentonitic clay several feet in thickness has been observed in the upper part of the Kiowa shale at outcrops in Clark County, Kansas. Chemical analyses of a few samples of Graneros shale indicate that the clay mineral montmorillonite is an important constituent, and in some cases the dominant clay mineral.

Age of Overlying Deposits

The area under discussion is that in which pre-Greenhorn Cretaceous beds comprise the bedrock. Surface outcrops, however, are by no means restricted to bedrock exposures. Over a considerable portion of the area the bedrock is covered by younger beds ranging from a few inches to several feet in thick-

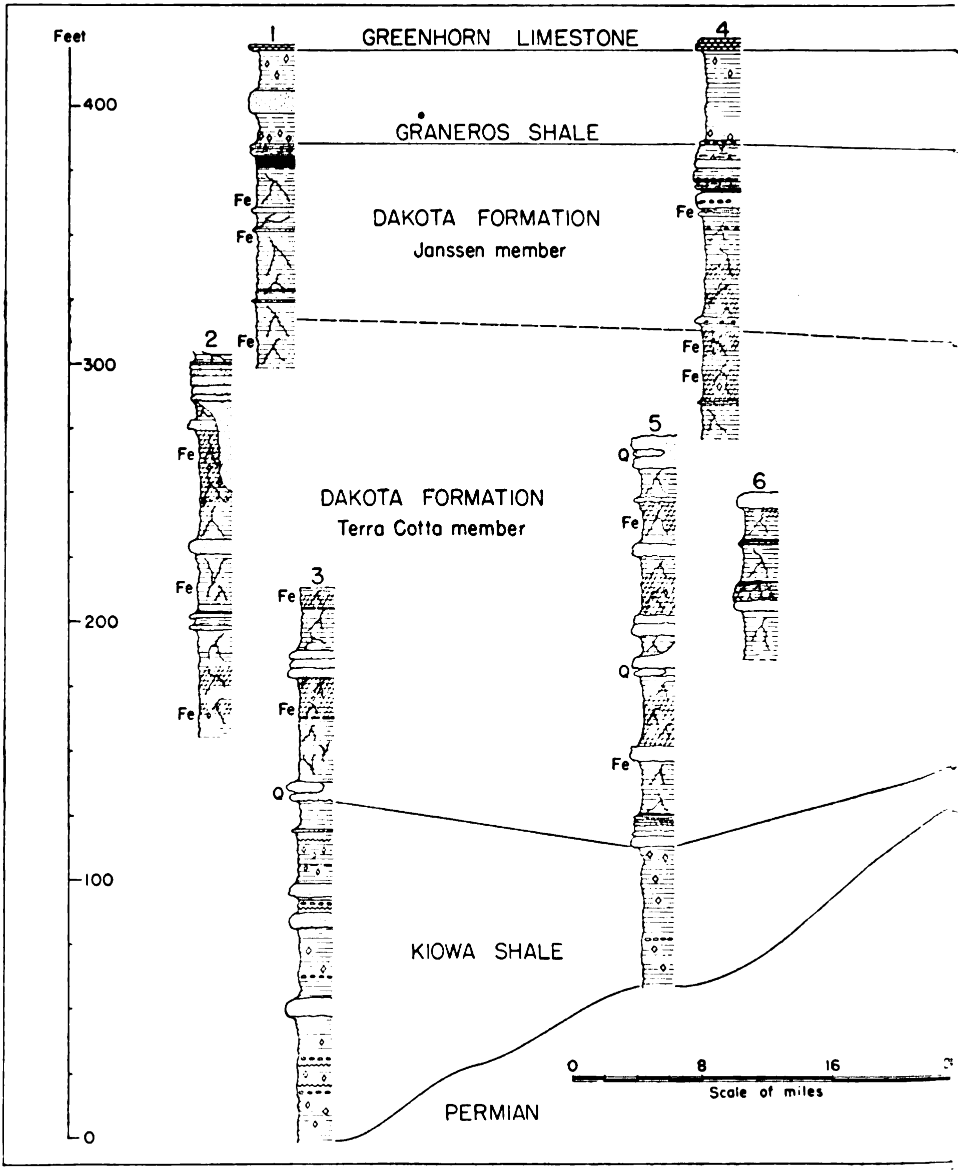
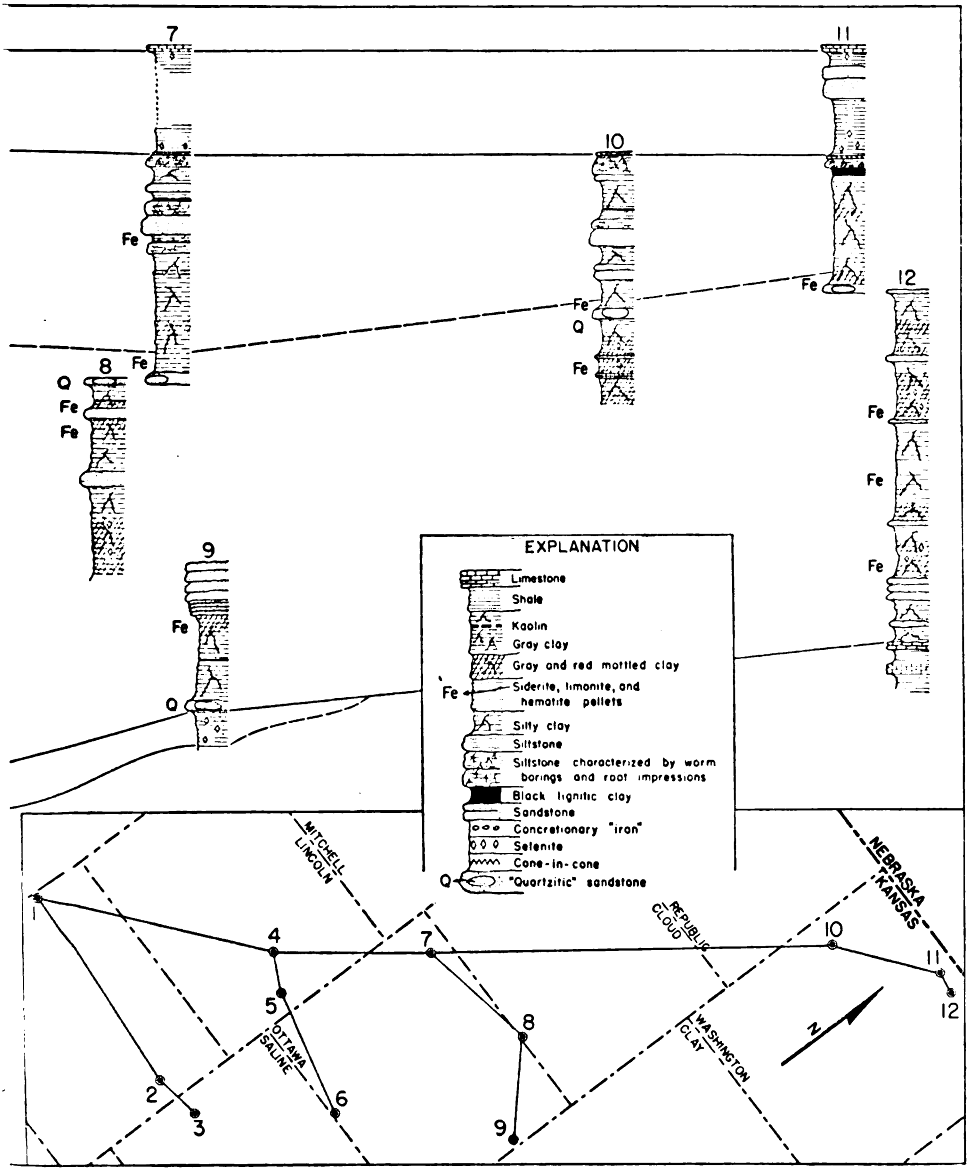


Fig. 1.—Correlated outcrop sections of the Creta



eous beds of central and north-central Kansas.

ness. These deposits range in age from Tertiary to very Recent, but those of Pleistocene age are quantitatively the most important. The Pleistocene beds include glacial deposits of several types, and loess, terrace, and alluvial deposits. The presence of these beds has an important bearing on the economic value of the clay deposits in the area. The younger beds conceal the Cretaceous clay beds over a large area, and in many places complicate the quantitative estimation of the clay reserves, due to the fact that the contact between the older and younger beds is an irregular erosional surface that has but little relation to the surface topography.

FIELD SAMPLING PROCEDURE

The first three months spent in the field were devoted to a preliminary study of a large part of the outcrop area in central and north-central Kansas, noting and spotting on maps the different types of clay, and the size and relative value of the deposits. Small trench samples were obtained and preliminary firing tests were made to guide subsequent work. From the information thus obtained, those locations which were the most promising from the standpoint of quality and quantity of clay were selected for further investigation.

When samples were obtained from creek banks, road cuts, and shale pits, as much as possible of the weathered or contaminated material was stripped from the surface. Then the sample from a U-shaped trench of uniform cross-section was cut into the cleaned face of the exposure. The weight of the samples varied from 25 to 75 pounds, depending upon the thickness of the bed sampled.

With few exceptions, a more detailed and intensive type of field procedure was employed in studying and taking samples from the clay beds of pre-Greenhorn Cretaceous age. Of these beds those of Dakota age were considered of primary importance, although samples were also taken of the underlying Kiowa shale and of the overlying Graneros shale.

Inasmuch as clean, representative samples can be obtained at very few places from surface outcrops of these beds, a state-wide W. P. A. project was set up to furnish the labor necessary to excavate pits from which samples of freshly exposed clay could be obtained. These pits were 6 to 10 feet long, depending upon the sur-

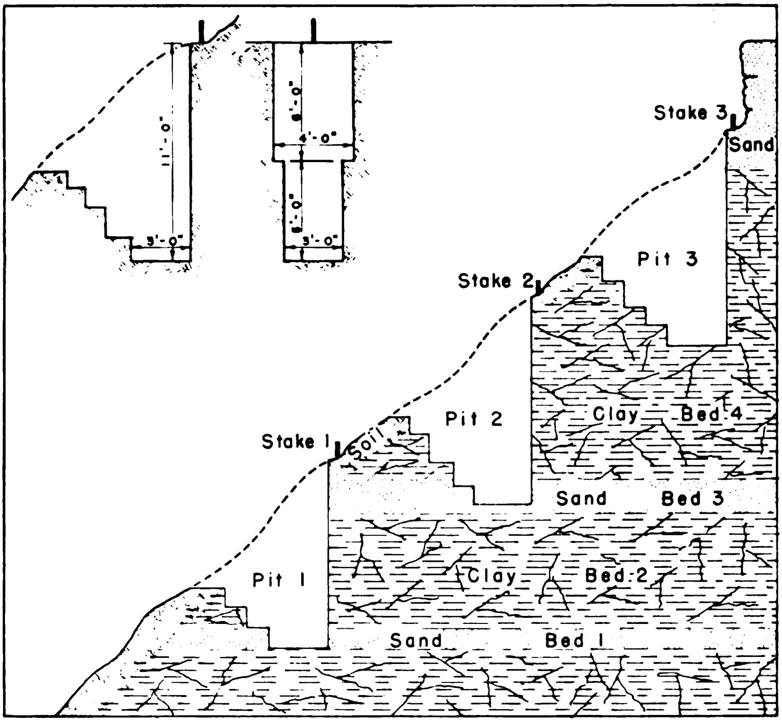


FIG. 3.—Diagram showing method of excavating the pits from which samples were obtained.

face slope, about 4 feet wide at the top, and 11 feet in depth at the vertical up-hill face. This face was kept vertical to permit accurate measurements and sampling. The long way of the pits was up and down the slope. For convenience in digging the pits and in sampling, the lower ends of the pits were inclined, and steps cut into them. As a foot-rest to be used when examining and sampling the upper part of the 11-foot vertical face of the pit, 6-inch benches were left along each side of the pit, about 6 feet from the top. A diagram of the arrangement of the pits is shown in Figure 3.

A complete vertical section of the beds to be sampled was obtained by "stair-stepping" the pits up the slope of a hill, wherever the topography permitted (Pl. 5A). Each successive pit was spaced 5 to 10 feet vertically above the next one below, thus allowing 1 to 5 feet overlap, which was sufficient in most cases to compensate for overburden consisting of soil, slump or weathered clay. Each pit was measured and different beds described according to type of clay or sand, bedding, texture, color, thickness, impurities, and other pertinent facts which could be noted. True elevations were run with the plane table and alidade to stakes set at the top of each pit which made possible accurate calculation of the successive overlap of each pit, and determination of the actual thickness of the deposit. The elevations obtained also facilitated the correlation of beds in adjacent localities.

Each bed represented a change of color or type of material. Numbering of beds started from the bottom of the lowermost pit and continued upward through the successive pits. Samples were taken after measurements and descriptions were recorded. The samples were collected on a 4 x 6 foot canvas laid in the bottom of the pit. Twenty-five to 100-pound representative samples of each bed were removed from the 11-foot vertical face by picking a V- or U-shaped groove of uniform width and depth down the face of each bed exposed.

Each sample was sacked and labelled according to county initial, location number, and bed number, with section, township, and range noted. Samples then were shipped to the Geological Survey laboratory at Lawrence.

This method of sampling proved to be very successful, since the sample was taken from a newly exposed face and surface contamination was eliminated. Comparisons by laboratory tests of samples taken from a surface trench and from pits at identical locations indicated that surface samples, even from a depth of a foot below the surface, were not to be relied upon.

Unfortunately it was necessary to fill up the pits after the measuring and sampling was completed. To obtain additional samples it would be necessary to dig new pits.

The field work proceeded by counties according to the availability of W. P. A. labor. Crews were digging in as many as three counties at one time. In a few counties no labor was available when the field work was in progress so that only preliminary field work was possible.

LABORATORY TESTING PROCEDURE

The laboratory testing of the samples consisted largely of investigations of the physical properties of the clays. The procedure approximates the steps taken in the commercial utilization of a clay—preparing a plastic mass of clay by adding water to the ground clay, forming shapes from the plastic clay, drying, and firing to various temperatures in a kiln. The properties noted in each step have been devised to present a definite picture of what may be expected of the behavior of each clay in commercial processing.

The procedure and methods used in this investigation follow as closely as possible the standards recommended by the Committee on Standards of the American Ceramic Society (Watts and others, 1928) and A.S.T.M. standard methods of test for apparent porosity, water absorption, apparent specific gravity, and bulk density of burned refractory products, designation: C 20-41.

The dry raw sample was crushed in a 3-foot pan mill, which pulverizes and thoroughly mixes the clay. The sample was then divided and a portion stored in fibre drums for future use. (Pl. 6A). The portion reserved for immediate testing was put in water to slake, after which it was hand blunged to a thick slip, and screened through a 20-foot mesh sieve. Excess water was removed on a plaster slab covered with cloth. When the water content of the clay had been reduced to secure the best consistency for molding, the clay was thoroughly "wedged"—that is, kneaded and pounded to produce uniformity and to work out included air.

The above procedure for the preparation of plastic clay is suited specifically to tests for pottery clay. Alternate procedures were used in the case of clays adapted to the manufacture of heavy clay products. The dry clay was crushed to pass a 20-mesh (or in some instances a 10-mesh) screen, and mixed with enough water to form a plastic mass. Comparison of test data obtained from both methods employed for the same sample indicates that the differences in results are negligible.

The plastic clay was shaped in hand molds into briquettes approximately 1-⅛ inches square in cross section and in two lengths, 3½ inches and 7 inches. Part of the longer bricks were used for the transverse strength tests. From 20 to 30 bricks were made from each sample of clay tested. Each brick was numbered for identification. Marks 7 cm apart were placed on the short bricks with a tram, and similar marks 14 cm apart were put on the long bricks.

An International de-airing extrusion or brick-making machine was acquired in 1946 (Pl. 6B). Sufficient water is added to clay to produce a stiff-mud consistency, after which it is pugged by passing it through the machine with the die removed. The pugged clay is then extruded through a 1-⅛ inch square die to form a continuous column 1-⅛ inches by 1-⅛ inches in cross-section. The column, or bar, is cut into 3½-inch or 7-inch lengths, forming test bricks having the same dimensions as the hand-molded bricks. These test bricks are shown on Plate 6B, bottom, center.

In general, test data obtained from machine-molded bricks vary somewhat from those obtained from hand-molded bricks. The differences are due chiefly to the fact that less water is required for extrusion than for hand-molding.

The 3½-inch plastic bricks are then weighed and the volumes determined by displacement in kerosene. The 7-inch bricks are weighed for water of plasticity determinations. The bricks are then placed on racks and dried at room temperature. The drying process is completed in a thermostatically controlled electric drier at 210° to 230° F.

The dried bricks are measured and weighed, and the volumes determined on the short (3½-inch) bricks. Five of the long (7-inch) bricks are broken in a transverse strength testing machine of our own design. The bricks are placed on a 5-inch span, with a load applied through a lever in the center of the span. This load is applied by running shot into a suspended bucket. When the brick breaks the stream of shot is automatically shut off.

The bricks are fired at an average rate varying from 100° to 150° F. per hour. Most of the firing was done in a fire-tube type of muffle kiln (Pl. 6C) using natural gas as fuel. For extremely high temperatures, and smaller tests a Globar type electric kiln was used (Pl. 6C). Temperatures are indicated and recorded in the process of firing by a thermocouple and recording pyrometer. The end-point of firing is determined by pyrometric cones placed in various parts of the kiln. After firing, the bricks are again weighed and measured. Thereafter the fired bricks are boiled in

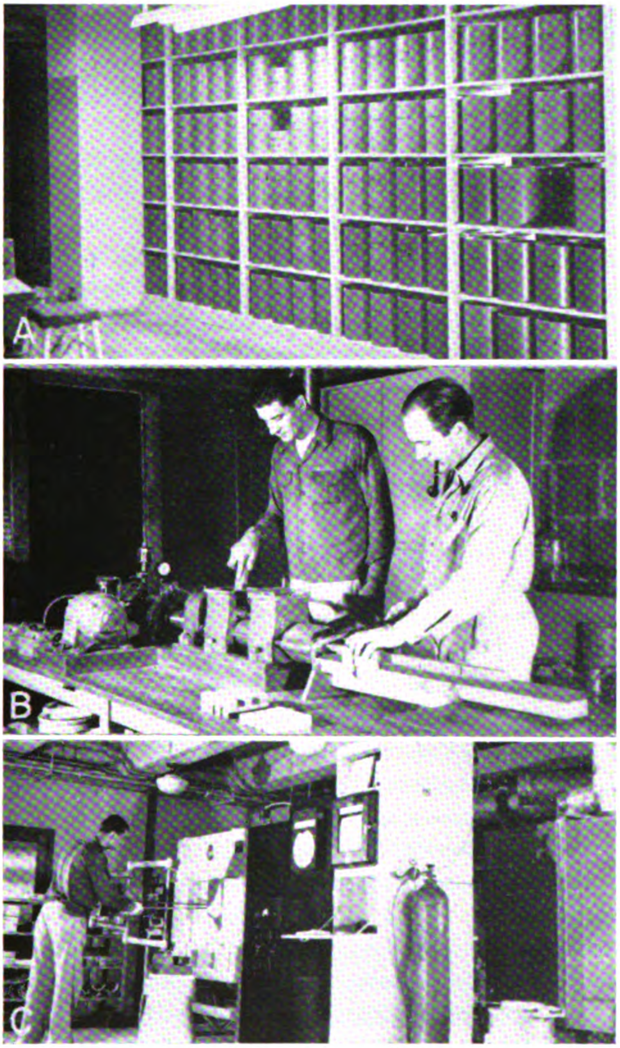


Plate 6.—*A*, A part of the clay sample file showing method of storing in fibre drums. *B*, De-airing extrusion, or brick-making machine used for making test bricks of clays intended for structural clay products. *C*, Kilns used in firing test bricks, and for other ceramic tests. (Left to right). Small electric kiln, large high-temperature electric kiln, controls and temperature recording instruments, and to extreme right a partial view of large gas-fired test kiln.

water for at least two hours and allowed to soak for 24 hours. The saturated bricks are then weighed both in air and in water. From the difference in weights the volume can be calculated, and the absorption can be calculated from the difference between the saturated weight and the dry fired weight.

All the clay samples are fired at increasingly higher temperatures until they are vitrified or until the maximum temperature attainable in our test kiln (cone 12-13 or 2,345° to 2,435° F.) has been reached. Normally the samples are fired to five different temperature levels, beginning with cone 06 to cone 04 (1,841° to 1,940° F.). The succeeding intervals are cone 02 to 01, cone 2 to 3, cone 4 to 6, cone 7 to 9, and cone 10 to 13.

From observation or by calculations based on data obtained in the series of tests the following properties are recorded and filed. In this report some of the less pertinent data are omitted from the description of specific samples.

ORIGINAL PROPERTIES

Type of clay.—The light-firing clays are classified as kaolin, ball clay, plastic fire clay, siliceous fire clay, and highly siliceous fire clay, according to the chemical composition and physical properties characteristic of these types of clay. Red-firing clays and shales are discussed separately.

Original color.—The color or colors of the raw clay before grinding are noted both in the field and the laboratory.

Visible impurities.—Particles of substances such as sand, iron, pyrite, limonite, siderite, gypsum, and lignite, which are easily visible without the aid of a microscope, are noted in the list of visible impurities.

Rate of slaking.—The data on slaking include both a rough estimate of the relative rate of slaking of the original sample in water, and also the exact length of time required to slake a 1-inch, hand-molded cube on a screen submerged in water. The first observation is useful in estimating the ease with which coarsely ground clay can be blunged in water, and the second indicates the bonding strength of the clay particles after molding into bricks or other forms. In the case of clays which slake easily when taken from the deposit the two rates of slaking will be approximately the same, but in the case of indurated clays they may differ widely.

Hardness.—The relative degree of difficulty experienced in crushing the original sample in the pan mill was used to estimate the hardness of the clay.

PLASTIC AND DRY PROPERTIES

Dry color of bricks.—The color of the dry brick will differ considerably from the original color of the clay if the clay contains streaks or splotches of different colors, because the clay is thoroughly mixed before it is made into bricks.

Plasticity.—This property is determined by handling the clay in the processes of preparation and molding, and is recorded as highly plastic, plastic, fairly plastic, lean (or slightly plastic), and very lean. These terms are relative to the two extremes as observed in handling more than 1,400 clay samples (Henry, 1942).

Workability.—The workability of a clay is judged from the ease or difficulty experienced in hand molding the test bricks. Such terms as "smooth," "sticky," and "crumbly" are employed in describing this property. Special machines have been used to make quantitative determinations of this property, but none was available for this investigation (Graham and Sullivan, 1939).

Drying behavior.—Warping, cracking, scumming, or cupping are recorded if they occur.

Slaking time.—This is the time required to slake a 1-inch hand-molded cube when placed on a screen and submerged in water. This property is discussed under original properties.

Water of plasticity.—This is the percentage of water present in the clay when the best consistency for molding has been obtained. Each clay has a water of plasticity range in the sense that it possesses the property of plasticity to the extent of deforming under pressure and retaining its shape after deformation with a water content which may vary by several percent. At the upper limit the clay is so soft that any further addition of water would cause it to flow of its own weight. At the lower limit the clay is so stiff that if any water were removed the clay would crack when deformed under pressure. When the lower limit has been passed it is not possible to roll a small cylinder of the clay on a smooth surface with the hand without causing small cracks to form in the cylinder as it is elongated by the pressure applied on rolling. We attempt to mold our test bricks just short of this condition, or when the minimum water of plasticity is reached. By using this method the data on all samples tested are comparable, and reproducible within narrow limits.

The water of plasticity is calculated from the formula

$$\frac{\text{Plastic weight} - \text{Dry weight}}{\text{Dry weight}} \times 100 = \text{Percent water of plasticity}$$

Shrinkage water.—Shrinkage water is defined as that portion of the water of plasticity which is driven off up to the point where shrinkage ceases. The balance is "pore water." The shrinkage water is therefore that portion which holds the clay particles apart. When the clay particles touch, the water remaining in the clay is driven off as pore water, but does not change the volume of the brick. These properties are important inasmuch as they determine to a large extent the behavior of the clays in drying, and give a clue to the problems which will be encountered in commercial utilization (Whittemore, 1942). Shrinkage water is calculated from the formula

$$\frac{\text{Volume plastic} - \text{Volume dry}}{\text{Weight dry}} \times 100 = \text{Percent of shrinkage water}$$

Pore water.—This property has been discussed under shrinkage water. It is determined by subtracting the shrinkage water from the water of plasticity.

Dry volume shrinkage.—The shrinkage of clay from the plastic to the dry state is a very important factor. Excessive shrinkage will eliminate a clay from many uses. The formula is

$$\frac{\text{Plastic volume} - \text{Dry volume}}{\text{Dry volume}} \times 100 = \text{Percent dry volume shrinkage}$$

Measured linear shrinkage.—This factor is determined from the decrease in distance in drying between the lines marked by a tram on the face of the plastic brick. Its function is the same as that of volume shrinkage. The formula is similar.

$$\frac{\text{Plastic length} - \text{Dry length}}{\text{Dry length}} \times 100 = \text{Percent measured linear shrinkage}$$

Calculated linear shrinkage.—This property is determined as a check on the measured shrinkage. Both should have the same value if all determinations are correct. The calculated shrinkage is more likely to be correct than the measured shrinkage, but the latter is a good check on gross errors in volume determinations. The calculated linear shrinkage is figured from the volume shrinkage.

$$100\left[\frac{\sqrt[3]{1+\%\text{ volume shrinkage}}}{100}-1\right]=\text{Percent calculated linear shrinkage}$$

Transverse strength.—The transverse strength of the long bricks broken by a load applied to the center of a 5-inch span is calculated as the modulus of rupture (M) from the formula

$$M=\frac{3\ Pl}{2\ bd^2}$$

where P = the total load in pounds at which the brick failed
l = the width of the span in inches
b = the width of the brick in inches
d = the depth of the brick in inches

FIRED PROPERTIES

Fired color.—Probably the most important feature of clay is its color when fired. Color alone determines many of the uses of a clay.

Firing behavior.—Warping, cracking, cupping, scumming, or bloating of the brick is recorded.

Volume shrinkage.—The fired volume of the brick is determined by weighing the saturated brick first in air, then in water. The difference in weight represents the volume of water displaced by the brick after making corrections for variations in the specific gravity of the water due to temperature variations. An accurate knowledge of the shrinkage of a clay is important from the standpoint of maintaining size tolerances in many commercial products. Excessive shrinkage is likely to be attended by cracking or warping. Little or no shrinkage indicates that the clay is underfired. The formula for volume shrinkage is

$$\frac{\text{Dry volume}-\text{Fired volume}}{\text{Dry volume}}\times 100=\text{Percent volume shrinkage (on firing)}$$

Linear shrinkage (measured).—Linear shrinkage is calculated from the formula

$$\frac{\text{Dry length}-\text{Fired length}}{\text{Dry length}}\times 100=\text{Percent linear shrinkage (measured)}$$

Linear shrinkage (*calculated*).—The formula for converting dry volume shrinkage to dry linear shrinkage is used to convert fired volume shrinkage to fired linear shrinkage. The function of the linear shrinkage (measured and calculated) in evaluating a clay is the same as that of the volume shrinkage. The relationships are the same as those discussed under plastic and dry properties.

Absorption.—The method of determining absorption has been described earlier under laboratory procedure. The percentage of water absorbed by a fired clay determines how hard it is fired or the degree of vitrification. Any fired product which is exposed to the weather must have a specified percentage of absorption to avoid disintegration due to freezing and thawing. Bricks with a high absorption will result in wet walls, and pottery with a high absorption will leak. Since the commercial specifications indicate the percentage of absorption allowed on most clay products it is quite easy to determine from this simple test the correct temperature at which to fire a clay for a certain type of product. The percent of absorption is calculated from the formula

$$\frac{\text{Weight of saturated brick} - \text{Dry weight of fired brick}}{\text{Dry weight of fired brick}} \times 100 = \text{Percent absorption}$$

Apparent porosity.—The apparent porosity is the relationship of the amount of water absorbed by the brick to its volume. Since the weight of water absorbed is given in grams it can be converted directly into cubic centimeters, so the water absorbed is an index of the volume of the open pore space in the fired brick. The formula used is

$$\frac{\text{Saturated weight} - \text{Fired weight}}{\text{Volume fired}} \times 100 = \text{Percent apparent porosity}$$

Apparent specific gravity.—This property approximates the true specific gravity in that the amount of open pore space, as indicated by absorption of water, is subtracted from the volume. The volume occupied by sealed pores does not enter into the calculation. The formula is

$$\frac{\text{Weight fired}}{\text{Volume fired} - (\text{Saturated weight} - \text{Fired weight})} = \text{Apparent specific gravity}$$

Bulk specific gravity.—Bulk specific gravity is the weight per volume of fired clay, including open and sealed pores. The bulk specific gravity is less than the apparent specific gravity. As the clay approaches vitrification the bulk specific gravity comes numerically closer to the apparent specific gravity. The specific gravity is useful to the ceramist in calculating the weights of clay materials. For example, brick with a bulk specific gravity of 2.0 will have a per-cubic-foot weight of 124.8 pounds. The formula for determining bulk specific gravity is

$$\frac{\text{Weight fired}}{\text{Volume fired}} = \text{Bulk specific gravity}$$

Hardness.—A steel file is the standard used in determining the hardness of a fired brick. The hardness is reported as softer than steel, steel hard, and harder than steel.

Transverse strength.—The transverse strength of the fired bricks is determined by the same method as for the unfired bricks.

Best firing range.—The firing range of each clay is estimated from a study of the fired properties such as shrinkage, absorption, specific gravity, and hardness. This range is commonly extended from the lowest temperature required to produce a steel-hard brick to the highest temperature it will stand without deforming or cracking or completing vitrification. A clay with a long firing range is much more useful than one with a short range, since most commercial kilns cannot be controlled within close limits.

Pyrometric cone equivalent.—The P. C. E. or pyrometric cone equivalent of a clay is determined by comparing its softening, or fusion, point with that of standard pyrometric cones. These are small tetrahedrons composed of ceramic materials consisting largely of clay and silica in the higher temperature range. The standard cones partially fuse, causing the tip of the cones to bend toward the base, at definite temperatures if heated at a specified rate under standard conditions. The clay cones to be tested are of the same size and shape as the pyrometric cones, and are mounted alternately with them on a circular plaque made of refractory materials. Our tests are conducted in a gas-fired furnace designed for this specific purpose by the American Refractories Institute. The tests conducted by us are in accordance with A. S. T. M. Standard C 24-42 (adopted in 1920; revised in 1942).

Inasmuch as this report is concerned chiefly with clays which, due to their refractory qualities, may be classed as fire clays, the P. C. E. of the samples tested is of primary importance in determining the maximum temperature at which a clay will be useful as a refractory. The P. C. E.'s of the various classes of fire-clay refractories have been designated by the American Society for Testing Materials. Inasmuch as the standards for siliceous fire-clay brick were not included in the 1941 definitions but were in those of 1935, the standards for both years are given in Table 2.

Other requirements, including permanent linear shrinkage and loss in the panel spalling test, are listed with the classification of the various types of fire clay, but are not included here because the results of such tests are not included in this report.

The Committee on Geological Surveys of the American Ceramic Society has proposed a much simpler general classification under which all clays having a P. C. E. of cone 19 or higher are classed simply as fire clays, and all those having a P. C. E. of cone 27 or higher are classed as refractory fire clays.

It is customary in ceramic work to refer to temperatures in terms of pyrometric cones. For the convenience of those not acquainted with the end point temperatures, or the softening point, in terms of the standard temperature scales, Table 3 is included. It is well to remember that the temperatures given are approximations only. The cones soften and bend over at various temperatures depending on the rate of heating, atmospheric conditions

TABLE 2.—*Standard classifications of fire-clay refractories*
A.S.T.M. designations C 27-35 (1935), C 27-41 (1941)

Class of fire clay	Pyrometric cone equivalent (minimum)	
	1935 standard	1941 standard
Super duty fire clay		cone 33
*High heat duty fire clay (silica content less than 70%)	cone 31	cone 31-32
High heat duty siliceous fire clay (silica content 70% or more)	cone 28	
Intermediate heat duty fire clay	cone 28	cone 29
Moderate heat duty fire clay	cone 26	
Low heat duty fire clay	cone 19	cone 19

*A fire clay having a silica content of more than 70 percent and a P.C.E. of not less than cone 29 may be classified as high heat duty siliceous fire clay, according to C 27-35 standards.

Table 3.—*Temperatures of fusion (end points) of standard pyrometric cones when fired rapidly and slowly*

(Fairchild and Peters, 1926, p. 738)

Cone number	When fired slowly (20° C. per hour)		When fired rapidly (150° C. per hour)	
	Degrees C.	Degrees F.	Degrees C.	Degrees F.
07	975	1787	990	1814
06	1005	1841	1015	1859
05	1030	1886	1040	1904
04	1050	1922	1060	1940
03	1080	1976	1115	2039
02	1095	2003	1125	2057
01	1110	2030	1145	2093
1	1125	2057	1160	2120
2	1135	2075	1165	2129
3	1145	2093	1170	2138
4	1165	2129	1190	2174
5	1180	2156	1205	2201
6	1190	2174	1230	2246
7	1210	2210	1250	2282
8	1225	2237	1260	2300
9	1250	2282	1285	2345
10	1260	2300	1305	2381
11	1285	2345	1325	2417
12	1310	2390	1335	2435
13	1350	2462	1350	2462
14	1390	2534	1400	2552
15	1410	2570	1435	2615
16	1450	2642	1465	2669
17	1465	2669	1475	2687
18	1485	2705	1490	2714
19	1515	2759	1520	2768
20	1520	2768	1530	2786
			180° C. per hour	
23			1580	2876
26			1595	2903
27			1605	2921
28			1615	2939
29			1640	2984
30			1650	3002
31			1680	3056
32			1700	3092
33			1745	3173
34			1760	3200

in the kiln or furnace, and the soaking period at the maximum temperature attained.

CHEMICAL ANALYSES

Chemical analyses are being run on all the more important beds of clay. For many purposes a chemical analysis is of no value to the user, but for the higher grades of clays it may be of considerable value, especially when mixing the clay in a carefully controlled batch. The user of fire clays is interested in the chemical analysis of a clay in that the ratio of alumina to silica, and the percentage of fluxes such as iron, calcium, and the alkalies have a direct bearing on the behavior of the clay under high temperatures. The classification of fire clays as "plastic clay" or "siliceous clay" is determined by the silica content. Clays containing 70 percent or more of silica are classed as siliceous fire clays.

The significance of the constituents determined by chemical analysis is discussed in detail under chemical properties of clay.

The methods of chemical analysis used in our laboratory conform in general to A.S.T.M. Standards, designation C 18-41, as outlined for fire clays. In some instances deviation from the A.S. T.M. standard seemed advisable. In such cases the procedures of well-established authorities usually were followed (Hillebrand, 1919; Washington, 1930; Hodgeman, 1935; Hills, 1939; Scott, 1939; Weeks, 1942; Hillebrand and Lundell, 1946; and Kalthoff and Sandell, 1946).

Russell T. Runnels, chemist for the Geological Survey, has developed some special techniques which he has found to be more accurate than established procedures. Some time within the year Runnels will publish a report on the methods he employs in analyzing for the various constituents in clay and will comment on the need for considering each clay sample a separate chemical problem.

REPORT OF TESTS

Although ceramic tests have been completed on most of the 1,400 samples collected for this investigation, no attempt will be made in this report to present in detail the data from all these tests. The properties of the various types of clay which were tested are described under separate heads. These types are classified by us according to their suitability or limitations for various commercial uses, although the chemical composition was used as a means of distinguishing the types.

The distinction between four of the types of clay listed in Table 4 is arbitrarily based on the alumina-silica ratio. In ceramic trade literature and in standard definitions, limits of chemical composition are not definite because physical properties usually are of primary importance. Within rather narrow limits, however, distinctions in chemical composition of types are recognized. According to A. S. T. M. standard definitions (A. S. T. M. Designation C 71-42) a plastic fire clay is "A fire clay of sufficient natural plasticity to bond nonplastic materials." A siliceous clay firebrick is defined as one having a silica content of 70 percent or more (A. S.T.M. Designation C 71-35). Thus the general division "plastic fire clay" of our classification conforms to A.S.T.M. Standards, at least by implication. The division of the plastic fire-clay class into two types—ball clays, and nonball clays—is based on the chemical composition of Tennessee and Kentucky ball clays as given in published analyses. In these analyses the minimum alumina content for the majority of ball clays listed is 25 percent, and has been so used by us. Other physical properties, such as shrinkage, fired color, and range of temperatures of vitrification have been considered. In general, however, any Dakota formation clay, excepting kaolins, having an alumina content above 25 percent has the physical characteristics of a ball clay.

With the exception of the red-firing clays, the order of the types represents a decreasing kaolinite content, and an increasing free silica content. If listed in order of abundance, with the most abundant first, the order would be: red-firing clay, siliceous fire clay, plastic fire clay (exclusive of ball clay), plastic fire clay (ball clay type), highly siliceous fire clay, and kaolin.

The sequence in which the clay types are listed, with the exception of the red-firing clay, is also in the order of normal occurrence of the clay beds. That is, kaolin is generally found at the top of a series of beds and the highly siliceous fire clay at the bottom. This is the reverse of the order of deposition, inasmuch as the lowermost beds must necessarily have been deposited first. It is assumed that this orderly sequence of beds is the result of uninterrupted deposition in relatively quiet, shallow water. Any sand which was carried in was laid down first, followed by silt, highly siliceous fire clay, and so on through to the finest-grained

TABLE 4.—*Chemical and physical properties of the types of Dakota formation clay described in this report.*

Type of clay	Approximate range of chemical composition			Physical properties		
	Silica (SiO_2), percent	Alumina (Al_2O_3), percent	Ratio Al_2O_3 to SiO_2, percent	Plasticity	Bonding strength	Range of temperature required to reduce absorption to 2% or less (pyrometric cones)
Kaolin	45.5—55.0	30.0—39.5	1:1.15 to 1:1.8	very slightly plastic	slight	9 to above 14
Ball clay type of plastic fire clay	55.0—65.0	25.0—34.0	1:1.6 to 1:2.6	very plastic	high	6 to 12
Plastic fire clay (exclusive of ball clay)	60.0—70.0	17.5—25.0	1:2.4 to 1:4.0	average	intermediate	8 to above 14
Siliceous fire clay	70.0—80.0	12.0—20.0	1:3.5 to 1:6.7	moderately plastic	fair	10 to above 14
Highly siliceous fire clay	above 80.0	below 15.0	1:5.3 and up	slightly plastic	slight	above 14
*Plastic red-firing clay	53.0—70.0	16.0—30.0	1:1.7 to 1:4.4	very plastic to average	average to high	
*Siliceous red-firing clay	above 70.0	below 20.0	1:3.5 and up	moderate to slight	fair to slight	

* Data on red-firing clay is not divided into plastic and siliceous type, but is given under the single heading "Dark buff-to red-firing clays."

plastic clay. It is believed that the kaolin was precipitated from colloidal suspension. Precipitation was brought about by a thickening of the suspension due to the absorption of water by the underlying beds and by evaporation. The consequent decrease in the total volume of water would favor precipitation both because of the increased ratio of solids to water and because of the increased concentration of salts which would produce flocculation. The kaolin beds are always massive in structure, and exhibit a pronounced conchoidal fracture. Unlike other Dakota formation clays the kaolin has some of the characteristics of a flint clay—that is to say it does not slake readily in water, and it is relatively hard. Fragments of kaolin can be found commonly on eroded exposures below the outcrop of the bed, or in streams several hundred feet down-stream from the outcrop. In many places no recognizable kaolin bed is found at the horizon normal for its occurrence, although the clay at this horizon is commonly highly aluminous, indicating a high kaolinite content.

Above the kaolin beds we have usually found a bed of nearly white, bright red and yellow mottled clay. This bed grades upward into a highly hematitic bed, which on the outcrop consists of granular aggregates of hematite and limonite in a matrix of clay, silt, and sand. The presence of the coarser sediments indicates an interruption of the previously undisturbed cycle of sedimentation. Probably fresh silt and sand which was brought into the lake or lagoon, carried down the remaining fine sediments and precipitated the ferrous iron compounds which had remained in solution. The precipitation of the iron could have been brought about by an increase in the silicic acid content of the water.

This orderly sequence of beds is repeated at various horizons throughout the thickness of the Dakota formation. It has been an aid both in stratigraphic correlation (Plummer and Romary, 1942) and in prospecting for valuable clay beds.

The clay samples described under the various headings were chosen to represent the range within the types, rather than the average. For this reason some of the clays described are from relatively thin and in some cases unimportant deposits. The extent and range in thickness of the types of clay will be given on subsequent pages. With the exception of kaolin all the types represented can be found in beds of thickness and extent far in excess of any commercial demands.

WHITE TO BUFF-FIRING CLAYS

Kaolin

The kaolin beds which were found in the Dakota formation are all relatively thin, ranging in thickness from a fraction of an inch to 18 inches. Individual beds vary greatly in thickness but usually have a considerable lateral extent. Although fine-grained and smooth to the touch, the kaolins do not crush as easily as the more impure clays. They slake in water with difficulty and are, in general, but slightly plastic.

Location and Occurrence of Samples Described

(El-14) The first sample described, No. El-14-04, was taken from a bed which occurs in the lower part of the Terra Cotta clay member. A total thickness of 73 feet of clay was sampled at this location (El-14) which is southwest of Carneiro, Ellsworth County (NE¼ sec. 25, T. 15 S., R. 7 W.)

Measured section from which sample El-14-04 was taken, NE¼ sec. 25, T. 15 S., R. 7 W., Ellsworth County.

Bed No.		Thickness, in feet
	Dakota formation	
	Terra Cotta clay member	
	Soil, clay, and sandy residual	2.3±
05.	Clay, silty, light gray with horizontal limonitic streaks and some red mottling; granular hematite toward top of bed	4.3
04.	**Kaolin, very light gray to white with some yellow joint stain; conchoidal fracture**	**1.5**
03	Clay, silty, lignitic, gray with some yellow stain; conchoidal fracture (siliceous fire clay)	1.5
02.	Silt, clayey, lignitic, with limonitic yellow streaks	0.5
01.	Clay, fine-grained, plastic, lignitic, gray to dark gray; occurs in thin beds; contains some pyrite (plastic fire clay)	6.9
		19.4

The thickness shown for bed 04 (1.5 feet) is the maximum found, although it extends laterally for several miles, thinning to as little as 0.1 foot in some places.

(L-30) The second sample described (L-30-4) was taken from a bed which occurs in the Janssen clay member. A series of 9 pits were excavated at this location (L-30), which is south of Barnard, Lincoln County (NE¼ sec. 32, T. 10 S., R. 6 W.)

Measured section of pit from which sample L-30-4 was taken, NE¼ sec. 32, T. 10 S., R. 6 W., Lincoln County.

Bed No.		Thickness, in feet
	Dakota formation	
	Janssen clay member	
	Sandstone, yellow, and residual	0.7
4.	**Kaolin, white, conchoidal fracture**	**0.6**
3.	Clay, silty, hard (siliceous fire clay)	2.0
2.	Siltstone, clayey, gray, to silty clay; contains thin bands of yellow sandstone	5.1
		8.4

Mineralogic Properties

A few of the thinner beds of kaolin are seemingly composed of pure kaolinite, although other clay minerals of the kaolinite group may be present. The most common impurity found in the kaolin is fine silt. Very small shotlike particles, or "oölites" of siderite or limonite were found in some samples. Limonitic stains on the irregular fracture joints are quite common. Locally, kaolin beds are stained bright red in irregular splotches. The hematite which produces this stain may be produced by the oxidation of pyrite after exposure to weathering conditions.

Chemical Properties

The theoretical composition of pure kaolinite is silica, 46.5 percent, alumina, 39.5 percent, and water, 14.0 percent, although the actual composition of the pure mineral is variable. Nevertheless, the purity of a kaolin sample can be determined approximately by comparing its chemical composition with that of the pure mineral. In Table 5 the analyses of two well-known high-grade sedimentary kaolins are given for comparison with the Kansas kaolins. The analyses of Kansas kaolin represent the extremes of composition found in the samples collected, ranging from 31.9 to 37.8 percent in alumina content.

In making comparisons from the above analyses the fact should be borne in mind that the Florida and Georgia kaolins have been beneficiated, whereas the Kansas clays are channeled samples taken from the pits, and are in no way treated or selected.

TABLE 5.—*Chemical composition of Kansas kaolins compared to Florida and Georgia kaolins*

(Analyses of Kansas samples by Raymond Thompson and Russell Runnels in laboratories of State Geological Survey)

(Figures are percentages)

Constituents	Kansas El-14-04	Kansas L-30-4	Florida	Georgia
Silicia (SiO_2)	55.35	45.83	46.30	45.30
Alumina (Al_2O_3)	31.90	37.75	37.70	39.14
Iron oxide (Fe_2O_3)	0.94	0.05	0.80	0.27
Titanium oxide (TiO_2)	0.60	0.34	0.50	1.54
Calcium oxide (CaO)	0.45	0.58	0.50	0.13
Magnesium oxide (MgO)	0.12	0.80	0.00	0.04
Potassium oxide (K_2O)			0.20	0.15
and		1.20		
Sodium oxide (Na_2O)			0.00	0.10
Ignition loss	10.97	13.41	13.70	13.71
	100.3	99.96	99.70	100.38

Ceramic and Other Physical Properties

The results of ceramic tests on two samples of kaolin, El-14-04 and L-30-4, are given in Table 6. The chemical analyses of these clays are given in Table 5.

The Kansas kaolins are comparable in quality to the well-known kaolins sold to the ceramic trade, but as a source of commercial quantities they are unimportant because of the thinness of the beds. If the beds were mined, however, with the underlying or overlying fire-clay beds, the quality of the fire clay would be increased considerably. For example, sample No. El-14-04 was taken from a 1.5 foot bed of kaolin which is underlain by 10.8 feet of siliceous and plastic fire clays.

It would be feasible for small potteries and pottery-making classes in schools of the State to use the kaolin from the Kansas beds in compounding glazes and in making pottery bodies.

Ball Clay (Type of Plastic Fire Clay)

The term "plastic fire clay" is commonly interpreted to include any refractory clay which is sufficiently "plastic" or fine-grained to have good bonding qualities. Because of the great range in physical and chemical properties, and therefore in application to commercial uses, we have divided the plastic fire clay class into two types, ball clays and nonball clays. The ball clays are defined by us to include all highly plastic clays having an alumina content of 25 percent or more or an alumina: silica ratio of 1:2.6 or less. The color of the clays on firing may range from white to buff.

In the field, ball clays often can be distinguished from the more siliceous types by the talclike smoothness of both the dry and the moist clay, or by the absence of grit, which can be detected by biting down on the clay. Illite shale, which cannot be classed as ball clay or plastic fire clay, may have these same characteristics, but

TABLE 6.—*Data on ceramic tests of kaolin samples El-14-04 and L-30-4*
(Figures given are percentages)

	Sample No. El-14-04	Sample No. L-30-4
Plastic and dry properties		
Dry color	white	very light gray
Plasticity	slightly plastic	slightly plastic
Water of plasticity	24.3	23.5
Shrinkage water	7.5	10.5
Pore water	16.7	13.0
Volume shrinkage	13.5	19.9
Linear shrinkage	4.0	6.0
Fired properties		
P.C.E. Best firing range	cone 13 to 16	above cone 6 to 18
Fired color	white	white
Firing behavior	checked	sound

Fired properties, No. El-14-04	Cone 07	Cone 5	Cone 9	Cone 13	Cone 16	Cone 18
Volume shrinkage	5.5	6.0	17.5	18.6	30.0	
Linear shrinkage	1.9	2.0	5.5	5.9	11.2	12.4
Absorption	19.7	20.7	14.3	13.2	4.5	5.7
Apparent porosity	33.4	35.1	28.0	26.2	10.6	
Transverse strength lbs./in^2				660		

Fired properties, No. L-30-4	Cone 06	Cone 5	Cone 9	Cone 13-14	Cone 18
Volume shrinkage	3.9	19.5	25.7	32.0	
Linear shrinkage	1.3	6.1	7.9	9.7	17.0
Absorption	20.2	12.3	8.0	3.8	2.2
Apparent porosity	34.3	24.8	17.6	9.2	

inasmuch as laboratory tests indicate that illite is a minor constituent of all Dakota formation clays examined, the ball clays of this formation can be fairly accurately identified by the simple field methods mentioned.

Field identification of illite or kaolinite clay or shale is practically impossible unless supplemented by laboratory tests. We have observed, however, that structure and color differences are useful if correctly associated with mineralogical differences. The kaolinitic clays lacking the red color due to hematite are white, neutral gray, or black. Whether or not these clays contain iron compounds, uniform tints of yellow, green, or blue are lacking, whereas the illite shale or clay usually has a uniform tint of yellow or yellow-green and in some cases looks faintly blue when contrasted with a neutral gray of equal intensity. These differences may be due to the fact that the iron of the illite mineral may be part of the molecule, but is always present as an accessory mineral in a kaolinitic clay. In general, illite is associated with a shale structure (Grim and Cuthbert, 1945). That is, very few true shales are kaolinitic, although a massive clay may be composed dominantly of illite, particularly if it has not been subjected to compaction.

Beds of plastic fire clay of the ball clay type are found at intervals throughout the thickness of the Dakota formation in Kansas, and with few exceptions they are found associated with the more siliceous types which commonly underlie those of the highest plastic fine-grained clay. Fairly extensive beds of ball clay having a thickness of as much as 20 feet have been found. However, the beds which have an enormous lateral extent and which are quantitatively the most important, range in thickness below the minimum for economical mining operations.

Location and Occurrence of Samples Described.

The ball clays described are grouped according to counties as follows: Cloud, samples C-27-5 and C-27-13a; Ellsworth, El-12-4 and El-52-3; Lincoln, L-38-5; Ottawa, O-6-3 and O-38-4; Russell, R-6-9 and R-6-11; Washington, W-5-5, W-5-A, W-19-2, and W-19-3 (Pl. 1).

(C-27) Two samples taken of the same clay bed at location C-27 are described in this report. Several other samples of the same bed were taken, as well as samples of more siliceous but refractory light-firing clays which occur below the bed represented by samples 5 and 13a.

Measured section of pits from which sample C-27-5 was taken, SE¼ sec. 13, T. 8 S., R. 2 W., Cloud County.

Bed No.		Thickness, in feet
	Dakota formation	
	Terra Cotta clay member	
	Soil and residual	1.0
6.	Clay, light gray mottled with bright red in irregular splotches; contains small nodules of hematite	4.0
5.	**Clay, gray and light gray with slight amount of yellow stain on joints in lower portion; has pronounced conchoidal fracture; contains leaf fossils, some lignite, and a slight amount of gypsum**	7.5
4.	Clay, gray plastic with some yellow stain in upper 2.0 feet; gray, silty, containing lignite particles in lower 2.3 to 3.4 feet. A lenticular sandstone having a maximum thickness of 0.6 feet occurs near the middle of this bed	5.8
3.	Sandstone, light gray to buff, fine- to medium-grained in upper 4.4 feet; lower 1.6 feet is gray lignitic silt to silty clay	6.0
		24.3

Sample C-27-13a was taken from the same bed as C-27-5, but from pits excavated about a half mile to the southwest. Sample C-27-13a was obtained after a few carloads of clay had been removed for use in manufacturing light-weight firebricks.

Samples C-27-5 and C-27-13a were both taken from groups of pits comprising a total of 16 pits which were excavated in an area about a half mile wide, and extending from the north to the south

Measured section in pits from which sample C-27-13a was taken, SW¼ sec. 32, T. 8 S., R. 2 W., Cloud County.

Bed No.		Thickness, in feet
	Dakota formation	
	Terra Cotta clay member	
14.	Silt to fine sandstone, with some gray clay; yellow, bright red, orange, and gray	4.6
13a.	**Clay, gray, plastic, with slight yellow stain. Massive, with pronounced conchoidal fracture on fresh exposure. Tends to weather platy**	10.8

13.	Clay, gray, slightly silty at top, plastic at bottom. Contains some yellow stain	1.5
12.	Clay, gray, silty, with some yellow streaks	2.8
11.	Sandstone, yellow, fine-grained, with some gray in top 0.6 foot. Silt, gray, lignitic, with some yellow color in lower 2.3 feet	2.9
		22.6

line of sec. 32, T. 8 S., R. 2 W. The beds sampled at this location comprise the northern part of the locally visible outcropping of a large and uniform deposit of clay. Samples 0-6-3 and 0-38-4, which will be subsequently described, were taken about 1 mile south of the Cloud-Ottawa County line, and are from the same bed of clay. The C-27 clay location is 6 miles west and 3 miles south of Miltonvale.

(El-12) Sample El-12-4 (location El-12, sample No. 4) was taken from a group of pits which were excavated 1 mile southeast of Carneiro, Ellsworth County. The bed of clay described occurs in the lower part of the Terra Cotta member of the Dakota formation. This bed and those immediately above and below it have been identified at other localities in Ellsworth County, including El-13, El-14, El-15, El-69, and El-90.

Measured section of pits from which sample El-12-4 was taken, NW¼ sec. 29, T. 15 S., R. 6 W., Ellsworth County.

Bed No.		Thickness, in feet
	Dakota formation	
	Terra Cotta clay member	
	Soil and residual	1.0
5.	Clay, light gray, fairly plastic with brown stain on joints	4.2
4.	**Clay; upper 3.0 feet gray, plastic, with leaf fossils; middle 1.0 foot light gray, slightly silty; lower 2.6 feet dark gray, fairly plastic, with a considerable amount of lignite and some leaf fossils**	**5.7**
3c.	Silt, clayey, nearly white, with yellow stain	2.4
3b.	Clay, fairly plastic, nearly white, with red mottling	2.7
3a.	Clay, silty, very light gray with yellow on joints	2.8
		18.8

The section given above was measured in two pits of a total of 11 which were excavated at this location.

(El-52) Sample El-52-3 (location El-52, sample No. 3) was taken from a series of six pits which were excavated about 3½ miles south of Kanopolis, Ellsworth County. This clay is unusual because its original color before firing is nearly white, and because of its extremely fine texture.

Measured section of pit from which sample El-52-3 was taken, NW¼ sec. 19, T. 16 S., R. 7 W., Ellsworth County.

Bed No.		Thickness, in feet
	Dakota formation	
	Terra Cotta clay member	
	Soil and residual	1.0
5.	Sandstone, yellow to brown	1.2
4.	Clay, plastic, lavender, red, gray, and yellow; contains some chunks of hematite	2.0
3.	**Clay, nearly white, plastic, very smooth**	2.8
2.	Sandstone to silt, gray to light yellow	3.6
		10.6

(L-38) L-38 is one of 19 locations in an area of approximately 12 square miles in western Lincoln and eastern Russell Counties. These locations are distributed along the bluffs bordering Hell Creek Valley and Saline River Valley from the mouth of Hell Creek northeast to a point 4 miles west and 1 mile south of Sylvan Grove. Of these 19 locations L-38 is the shortest distance from Sylvan Grove.

The clays sampled in this area are from the Janssen clay member and the upper part of the Terra Cotta clay member of the Dakota formation. Despite the fact that silt and sandstone beds are abnormally thick in this area, the available tonnage of light-firing refractory clay is above the average of that found in the upper part of the Dakota formation. This is due largely to the fact that the beds of silt and sandstone are thick but few in number, whereas in many places several thin beds of sand or silt are distributed throughout the section, thus breaking the usable clays into beds too thin for economical mining operations. Beds similar to those described at location L-38 occur throughout this area.

Beds 4 and 6 at this location differ from bed 5 only in that they have a somewhat higher iron content. Bed 4 fires to a buff color, and bed 6 to colors ranging at various temperatures from cream to light buff. Test bricks made up of all three samples mixed in proportion to the thickness of the beds fired to colors ranging from

Measured section of pits from which sample L-38-5 was taken, NE¼ sec. 19, T. 12 S., R. 10 W., Lincoln, County.

Bed No.		Thickness, in feet
	Dakota formation	
	Terra Cotta clay member	
7.	Sandstone, hematitic	0.4
6.	Clay, plastic, light gray with slight yellow stain	3.4
5.	**Clay, plastic, light gray with very little yellow stain, but with slight amount of sulfur yellow on joints; contains lignite particles and lignitized leaf fossils**	**7.2**
4.	Clay, identical to bed 5 except for more yellow stain	3.7
3.	Clay, plastic, gray to light gray with a few thin yellow streaks; some concretionary limonite in bottom 1.0 foot	3.2
2b.	Sandstone, fine-grained, yellow and brown; contains thin streaks (1 to 3 inches) of clay at oblique angles	3.4
2a.	Sandstone, limonitic and hematitic, grading to nearly pure hematite at bottom	1.6
1.	Clay, plastic, gray with yellow bands	3.2
	Total thickness of section measured	26.1

cream to light buff at low and intermediate temperatures and to a gray at cone 12. This combination of beds 4, 5, and 6 (L-38-A), having a total thickness of 14.3 feet, is an excellent plastic fire clay suitable for use in manufacturing refractories and structural units.

(O-6) Clay location O-6 is about 1 mile south of location C-27 described above. Bed 3 of location O-6 (Sample No. 0-6-3) is from a different outcrop of the same bed of clay as C-27-5 and 6-27-13a.

Measured section of pits from which sample O-6-3 was taken, SW¼ SE¼ sec. 5, T. 9 S., R. 2 W., Ottawa County.

Bed No.		Thickness, in feet
	Dakota formation	
	Terra Cotta clay member	
5.	Residual and mixed yellow and gray silty clay; contains chunks of hematite	1.1
4.	Clay, silty, gray and yellow, with sandy streaks	2.4
3.	**Clay, plastic, light gray with very little stain; conchoidal fracture**	**5.3**
2.	Clay, plastic, gray, with some yellow stain; except for such stain nearly identical to bed 3	2.6-3.9
1.	Silt to silty clay, gray, with some yellow streaks	10.2
		21.6-22.9

Bed 2 of this location is a ball clay slightly less pure than bed 3, but fires to a cream color. Bed 1 is quite siliceous, but an excellent refractory clay, firing to colors ranging from ivory to cream.

(O-38) Clay location O-38 is approximately 650 yards southeast of O-6. Bed 4 of location O-38 correlates with bed 3 of location O-6, and with the C-27 beds mentioned above.

Measured section of pits from which sample O-38-4 was taken, NW¼ NE¼ sec. 8, T. 9 S., R. 2 W., Ottawa County.

Bed No.		Thickness, in feet
	Dakota formation	
	Terra Cotta clay member	
	Residual, containing much hematite	1.0
6.	Clay, silty, yellow, light gray, and some red, with some hematite	1.4
5.	Clay, plastic, light gray with moderate amount of red, brown, and yellow mottling	6.0
4.	**Clay, plastic, light gray with almost no stain; slickensides were found on small joints; contains some lignite particles**	**6.2**
3.	Clay, slightly silty, gray with almost no stain except slight amount of yellow and pink in lower 0.6 foot; contains lignite particles	2.3
2.	Clay, slightly silty, gray with some irregular streaks of fine sand stained lightly with pink and yellow	3.3
1.	Clay, very silty, dark gray, lignitic; contains a few thin yellow sandy streaks	3.5
		23.7

Although the results of tests will be given only for sample O-38-4, there are other beds of high-grade clay occurring below those selected for description as a typical ball clay. Beds 1, 2, and 3 at location O-38 are plastic to siliceous fire clays ranging in quality from fair to excellent.

(R-6) Location R-6 is one of five locations (R-4, R-5, R-6, R-7, and R-8) which were closely spaced on the bluffs bordering the Saline River Valley near the Russell-Lincoln County line. Pits were also excavated for sampling at 15 other locations in this general area, which is described in greater detail in the discussion of plastic fire clays under location L-38. Clays similar to those described in the R-6 section were found throughout the area.

Beds 2, 3, 4, 5, 6, and 8 of location R-6 were also sampled and tested. These clays are suitable for a variety of uses. Bed 2 is prob-

Measured section of pit from which samples R-6-9 and P 6-11 were taken, NE¼ NW¼ sec. 25, T. 12 S., R. 11 W., Russell County.

Bed No.		Thickness. in feet
Dakota formation		
	Janssen clay member	
12.	Silt to fine sandstone, gray and yellow; contains some pyrite	3.9
11.	**Clay, plastic, gray to dark gray; contains lignite particles and lignitized remains of roots and leaves**	5.7
10.	Clay, plastic, yellow and gray mottled	2.0
9c.	**Clay, plastic, nearly black, with some sulfur yellow stain; contains lignite particles and some selenite**	4.2
9b.	**Clay, plastic, gray with very slight amount of yellow stain**	3.2
9a.	**Clay, plastic, nearly black**	0.4
8.	Clay, silty, light gray with slight yellow stain, and a small amount of selenite (highly siliceous fire clay, ivory to nearly white when fired)	4.2
7.	Sandstone and silt, clayey, gray and yellow	2.0
6.	Clay, plastic, gray with red and yellow mottling which varies laterally in amount	6.6
5.	Clay, plastic, gray to dark gray with some red and yellow mottling	11.2
	Terra Cotta clay member	
4b.	Clay, plastic, light gray with brown and red mottling; contains hematite and limonite "shot" and granular hematite in elongated vertical masses	6.1
4a.	Clay, silty, gray, red, and yellow; contains granular hematite and hematite "shot" in upper 3.0 feet (4a plus 4b fires dark buff)	5.5
3.	Clay, very plastic, gray with slight amount of red mottling and yellow on slickenside joints; contains some selenite (brown-firing)	5.5
2.	Clay, plastic, gray with trace of red mottling (cream to buff-firing)	5.9
1.	Clay, silty, grading downward to clayey sandstone, gray and yellow	4.2
		70.6

ably a ball clay, and fires to light colors. Bed 3 has all the characteristics of a ball clay except the fired color. It fires to a dark brown at vitrification. Bed 4 fires to a dark buff despite the high percentage of hematite found in the clay. Probably iron specks would appear if it were fired in a slightly reducing atmosphere. Bed 5 has the properties of a ball clay but fires to an orange buff when vitrified (described under dark-buff to red-firing clay). Bed

6 is a good red-firing clay, and bed 8 is a highly siliceous fire clay which fires nearly white at cone 8.

These clays crop out on a steep-sided bluff, and the hill slopes back steeply from above the top of bed 12. For this reason the clays could not be removed for any considerable distance back into the hill without running into excessive overburden. By contouring along the hill, however, large tonnages of clay could be mined inexpensively.

(W-5) Five beds of clay were sampled at location W-5, 9.4 miles north of the town of Washington, in Washington County. Beds 3, 4, and 5 are unusually plastic ball clays very similar in physical and chemical characteristics. These three beds were tested separately, but were also combined into one sample, labelled W-5-A, for the routine tests, the results of which will be included in this report. The results of the tests on bed 5 will also be reported. The sample taken from this bed had a lower iron content than beds 3 and 4, and therefore fired to a lighter color.

This same series of beds was sampled at location W-17, about one-fourth mile northeast of location W-5. They probably also correlate with those at location W-19, described below, and possibly with W-24 (SE¼ SW¼ sec. 8, T. 1 S., R. 3 E.)

Measured section of pits at location W-5 from which samples W-5-A and W-5-5 were taken, NW¼ SE¼ sec. 14, T. 1 S., R. 3 E., Washington County. Bed A extends from the bottom of bed 3 to the top of bed 5.

Bed No.		Thickness, in feet
	Dakota formation	
	Terra Cotta clay member	
6.	Clay, very light gray and bright red mottled with vertical streaks which are highly hematitic; also has a slight amount of lavender color, and small spheroids of hematite, siderite, and limonite. A 1.5 yellow streak occurs near center of bed. In portions of the bed the red and light gray color occurs in alternating evenly spaced bands 1/32 to 1/8 inch wide	8.3
5.	**Clay, plastic, light gray, with some yellow stains; tends to thin bedding, especially on weathered surfaces; contains some lignite and a small amount of selenite**	**4.0**
4.	**Clay, plastic; upper 6.4 feet light gray with very light brown mottling; lower 2.8 feet rather dark gray with some yellow joint stain and light-brown mottling**	**9.2**

3.	**Clay, very plastic, dark gray with very little stain; tends to thin bedding; contains lignite particles and flinty concretions toward bottom**	3.4
2.	Clay, plastic, yellow and light gray; contains lignite particles and some limonitic concretions	4.7
1b.	Silt, gray and yellow	2.5
1a.	Clay, silty, gray with a small amount of lignite	4.0
	Total thickness of section	33.6
	Total thickness of bed A	16.6

(W-19) Clay samples No. W-19-2 and W-19-3 (beds 2 and 3 of location W-19) were sampled from a series of nine pits. Only three of these pits are described in the measured section which follows.

Measured section of pits from which samples No. W-19-2 and W-19-3 were taken, Cen. S½ SW¼ sec. 28, T. 1 S., R. 3 E., Washington County.

Bed No.		Thickness, in feet
	Dakota formation	
	Terra Cotta clay member	
	Soil and residual	1.5
4.	Clay, fairly plastic, light gray, with a considerable amount of yellow in horizontal bands	3.0
3.	**Clay, plastic; upper 2.4 feet gray with slight yellow strain, contains lignite particles; next 1.8 feet light gray with much yellow stain; lower 7.0 feet gray with some horizontal yellow streaks, and a considerable amount of yellow stain toward bottom. Thin bedding shows on weathered surfaces**	11.2
2.	**Clay, fairly plastic, gray with some yellow stains; contains lignite particles (a siliceous fire clay)**	7.4
1.	Clay, slightly silty, yellow with some gray	0.7
		23.8

With the exception of an unusual amount of yellow color, the physical characteristics of bed 3 are probably more truly typical of a ball clay than any others here reported. These characteristics were not so clearly indicated by field observation as they were by plasticity in molding, and by the drying and firing behavior, which will be discussed later in detail. The extreme smoothness of texture, fine grain, and plasticity, however, were readily detected in the field. Although bed 2 is a plastic fire clay it is included here for convenience of comparison.

These same beds were sampled about 200 yards east of the pits described. Apparently the same clay also crops out about one-half mile northeast in the NW¼ SE¼ sec. 28, T. 1 S., R. 3 W. Adverse weather conditions prevented digging pits at this outcrop, and also prevented further exploration to determine the local extent of the deposit.

Mineralogic Properties

The dominant constituents of the Kansas ball clays are kaolinite and finely divided quartz. Illite is a minor constituent which is probably lacking entirely in some of the clays, but may comprise as much as 25 percent of the clay minerals present, according to Ralph E. Grim, Petrographer, State Geological Survey of Illinois (personal communication). Variations in the proportion of illite to kaolinite would logically account for differences in plasticity, drying shrinkage, and firing shrinkage which are not due to differences in chemical composition or particle size.

In general, the particle size of both the clay minerals and the quartz is very small. After being thoroughly dispersed in water less than 1 percent of the total weight of the sample failed to pass a 200-mesh screen on most of the samples so tested. In a few cases as much as 5 percent remained on the 200-mesh screen. This material usually consists of aggregates of fine particles, and iron compounds such as siderite, limonite, and hematite, and in a few instances pyrite and selenite.

Sedimentation tests were made on several samples of ball clay. After thorough dispersion in 75 to 85 percent water to 15 to 25 percent solids by weight the suspensions were allowed to settle without agitation for varying lengths of time. With dispersions in which the pH was 7.0 or higher, 40 to 55 percent of the solids remained in suspension for 26 hours. Theoretically this fraction should consist of particles 1 micron in diameter or smaller. Chemical analyses indicate that this fraction is composed dominantly of kaolinite, whereas the settlings consist largely of quartz, although some of the clay is carried down with the coarser particles. By repeating this sedimentation process on the settlings, the materials remaining in suspension after 26 hours are again found to be composed chiefly of kaolinite. As much as 85 percent of the kaolin in the original samples can be separated from the quartz and other coarser or heavier fractions by this method. Therefore, at least 85 percent and probably a much higher percentage of the clay minerals in the ball clays are present in particle sizes 1 micron or less in diameter.

Minute amounts of ilmenite, rutile, tourmaline, and zircon have been identified in samples examined by R. F. Rea, Ceramist, for the Denver Fire Clay Company.

Many of the clays sampled have the physical characteristics of ball clay but cannot be so classified because of the large amount of finely divided hematite and limonite which they contain. The original color of these clays is yellow or red or with red and yellow mottling. Such clays fire to colors ranging from very dark buff to red, and are therefore described in the chapter on red firing clays.

Coarse aggregates of hematite, limonite, or siderite are also found in the clays in the form of small shotlike particles, or in vertical and oblique seams and along bedding planes. In many cases impurities of this type can be eliminated from valuable clays by selection in mining, or by screening, but if they cannot be removed the clay is suitable only for structural clay products.

The gray color of the ball clays is due to the presence of finely divided carbonaceous material, which may be entirely lacking in the white clays, or be present in considerable amounts in the nearly black clays. Lignitized wood is commonly present in small chunks scattered at random throughout the clay. The well-preserved leaf fossils which are characteristic of all Dakota formation clays are composed of carbonaceous material which is probably similar to the lignite.

Chemical Properties

For the purposes of this report plastic fire clays having an alumina content of 25 percent or more and an alumina-silica ratio of 1:2.6 or higher are defined as ball clays, providing of course, that their mineralogic and physical properties are those of a ball clay. The ball clays included in Table 10 have an alumina-silica ratio ranging from 1:1.6 to 1:2.6 (Table 4). The iron oxide content of some of the ball clays here discussed slightly exceeds the usual limits of commercial ball clays which are used in whiteware, porcelain, and similar products. For marketing purposes the clays having the higher iron content would probably be classified under the broader term plastic fire clays or under the more specific terms wad and sagger clays. Chemical analyses of clays sold by the

TABLE 7.—*Chemical composition of Kentucky and Tennessee sagger, wad, and plastic fire clays* (Figures are percentages)

Constituents	Tennessee XX	Kentucky Standard sagger	Kentucky No. 6 plastic fire	Light Monroe wad
SiO_2	59.40	51.50	63.72	65.80
Al_2O_3	27.20	30.84	26.40	21.62
TiO_2	1.60			1.28
Fe_2O_3	0.72	9.90	0.80	1.54
CaO	0.60	0.51	0.38	0.34
MgO	0.22	0.23	0.20	0.40
K_2O	0.68	1.26	0.75	0.38
Na_2O	0.36	0.45	0.49	0.39
Ign. loss	9.39	14.90	8.29	8.04

Kentucky-Tennessee Clay Company are given in Table 7 for purposes of comparison.

The chemical composition of the commercial types of clays given in Tables 7, 8, and 9 is not distinctive. Comparisons will reveal that overlapping occurs to such an extent that it is impossible to distinguish a ball clay from the more common plastic fire clays by chemical analyses alone. It is obvious, therefore, that the classification of the producer is based on physical properties revealed only by actual use in manufacturing ceramic ware, or under test conditions closely simulating such use. It should be born in mind also in comparing Kansas clays with the commercial clays listed that the latter were carefully selected in mining to eliminate impurities, whereas the Kansas clay samples are representative of the entire thickness of the beds.

TABLE 8.—*Chemical composition of Kentucky and Tennessee ball clays* (Figures are percentages)

Constituents	Kentucky Old Mine No. 4	Kentucky K. T. Ivory ball	Tennessee No. 9 ball	Tennessee No. 1 SGP ball
SiO_2	51.65	57.93	51.64	47.00
Al_2O_3	31.24	26.43	29.38	37.83
TiO_2	1.72	2.37	1.82	1.20
Fe_2O_3	1.17	0.69	1.01	0.71
CaO	0.20	0.19	0.65	trace
MgO	0.50	0.40	0.77	0.20
K_2O	0.36	0.08	1.30	0.10
Na_2O	0.58	0.37	0.43	0.20
Ignition loss	12.13	11.47	13.38	12.50

The range of chemical composition of Kansas ball clays is not so great as that of the Kentucky and Tennessee ball clays given in published analyses (Tables 9 and 10). For example, the alumina content of possibly 90 percent of the Kansas ball clays ranges from 26 to 30 percent, with a maximum of 33 percent, whereas the alumina content of the Kentucky-Tennessee ball clays ranges from 24 to 38 percent, with a fairly even distribution within this range.

Ceramic and Other Physical Properties

The results of standard ceramic tests on the ball clays discussed are listed in Table 11. Data on higher temperature firings on some samples were impossible to obtain on test bricks made from 100 percent raw clay. This was because of the extreme density of these clays, which resulted in black-coloring, cracking, or bloating at temperatures of cone 4 or higher. By calcining 50 percent of the sample, and mixing this grog with the plastic clay it was possible to fire the test bricks to cone 13-14, the maximum temperature obtainable in our test kiln, without overfiring. The plastic and drying as well as the fired properties of the grogged bricks differed markedly from those made from 100 percent plastic clay. Specifically, the shrinkage values were smaller, and the absorption and porosity values higher. The data for sample C-27-13a were obtained on test bricks containing 50 percent grog which was passed through a 30- and rested on an 80-mesh Tyler screen. Sample C-27-5 was tested with bricks containing 100 percent plastic clay.

Table 9.—*Chemical composition of nine Tennessee ball clays* (Whitlach, 1940, pp. 341-343) (Figures are percentages)

Constituents	Test 298	Test 299	Test 301	Test 302	Test 310	Test 311	Test 322	Test 385	Test 387
SiO_2	68.20	45.60	52.23	50.67	60.14	54.62	57.44	56.22	54.99
Al_2O_3	24.05	38.70	30.79	32.24	25.96	30.83	33.63	29.89	30.01
Fe_2O_3	0.15	1.00	0.90	0.89	0.20	0.31	0.12	0.97	1.14
TiO_2		1.04	1.38	1.47	0.34			1.97	1.58
CaO		0.12	0.18	0.65	0.33	0.09	0.12	0.26	0.23
MgO		0.20	0.38	0.41	0.38	0.16	0.05	0.24	0.41
K_2O		0.25	1.16	1.20	0.30	0.11	0.60	0.79	1.18
Na_2O		0.42	0.74	0.52	0.72	0.42			
Ign. loss	6.90	12.81	11.48	11.75	11.64	13.50	8.00	9.90	10.16
Total	99.44	100.14	100.24	100.10	100.01	100.04	99.96	100.24	99.70

Inasmuch as sample C-27-13a is almost identical to C-27-5, the effect of adding 50 percent grog can be noted readily by comparing the data on these two samples as given in Table 11.

The modulus of rupture (transverse strength) of the fired samples is not included in Table 11. Tests were made on bricks fired to near vitrification. The modulus of rupture varied for the various samples from 1,800 to 5,800 pounds per square inch. In general the values obtained were somewhat erratic because of structural defects in the test bricks due to the hand molding, and defects which occurred during firing due to incomplete oxidation, or release of gases in the close-textured clays. Extremely fine-grained plastic clays of this type are ordinarily tested by making bricks containing 50 percent flint. We have avoided this method because of the belief that the results obtained have but slight significance. Significant data can be obtained by including the clay to be tested in a standard commercial body. Usually a whiteware or porcelain body is chosen for the tests, but we plan in our tests to continue the use of a body consisting of 50 percent plastic clay and

TABLE 10.—*Chemical composition of 12 Kansas ball clays described in this report* (Analyses by Raymond Thompson and Russell Runnels)

	Constituents, percent								
Lab. No.	Silica (SiO_2)	Alumina (Al_2O_3)	Iron oxide (Fe_2O_3)	Titanium oxide (TiO_2)	Calcium oxide (CaO)	Magnesium oxide (MgO)	Potassium and sodium oxides (K_2O Na_2O)	Ignition loss	Total determined
C-27-5	59.60	26.71†	1.44	....	0.22	0.64	3.88	7.80	100.29
C-27-13a	57.94	27.35	1.79	0.13	0.62	0.47	0.87	9.71	98.75
El-12-4	61.40	26.74†	1.67	....	0.36	0.27	0.64	9.41	100.49
El-52-3	55.76	33.06	0.97	0.34	0.31	0.50	0.42	8.87	100.23
L-38-5	62.96	25.25	0.96	0.57	0.44	0.48	1.71	6.79	99.16
O-6-3	60.41	26.93†	1.41	....	0.31	0.76	2.25	7.65	99.72
O-38-4	61.62	26.46†	1.12	....	0.35	0.50	2.90	7.28	100.20
R-6-9	61.81	26.45†	1.28	....	0.37	0.64	1.98	8.97	101.40
R-6-11	61.94	25.48†	2.86	....	0.53	0.26	2.03	7.68	100.68
W-5-5	62.02	26.54†	1.52	....	0.39	0.65	3.19	7.45	101.76
W-5-A	59.76	26.15	2.18	1.06	1.27	1.35	2.70	7.20	99.67
*W-19-2	66.95	21.57	1.05	1.76	0.36	0.19	1.83	6.48	100.19
W-19-3	56.74	25.24	2.06	2.27	0.54	1.37	3.42	7.50	99.14

*Plastic fire clay included for reasons explained in text.
†Includes titanium oxide.

50 percent grog made from the same sample. This approximates a standard mixture for use in manufacturing firebricks and other refractories.

The estimate of the best firing range as given in Table 11 is based on the behavior of the test bricks in our laboratory kiln. The lower limit chosen is that at which the absorption is approximately 10 percent. The upper limit is the maximum temperature at which sound but vitrified bricks were obtained. The maximum temperature practicable for grogged bricks is much higher than that shown in the table. Hand thrown and cast pottery can also be fired to higher temperatures than the test bricks, largely because of the thinness of the cross-section, which permits complete oxidation. In general, clays which could not be fired above cone 5 in the form of test bricks could be fired to temperatures ranging from cone 8 to cone 11 when made into pottery. Grogged bricks can be fired to even higher temperatures. Inasmuch as most of the ball clays have a P. C. E. of about cone 27 it is evident that defects occurring in firing are caused by difficulties arising from the close texture of the material rather than a low temperature of fusion.

Dakota formation clays from a few localities have been used in the manufacture of glazed structural tile, face brick, and refractories. These bricks or tiles were extruded from a de-airing pug mill and fired in large down-draft kilns. Data obtained from the manufacturing processes were compared with our laboratory data. Values obtained on drying characteristics were comparable. Shrinkage, absorption, and porosity on firing the test bricks, however, were slightly higher than that obtained on the commercial products. To obtain identical absorption and porosity values the test bricks had to be fired about two cones higher than the others. This increased the spread of the shrinkage values. The differences are probably due largely to the methods of plastic forming. The test bricks were hand molded, and despite the greatest care, contained minute voids which increased the absorption and pororsity on firing. The large size of the commercial units no doubt had a bearing on the differences in value, particularly the shrinkage on firing.

Inasmuch as ball clays can be vitrified within the maximum temperature range of our experimental kiln, the data on firing are more complete than is true of the other types. Characteristic changes with temperature are also more exaggerated in the case

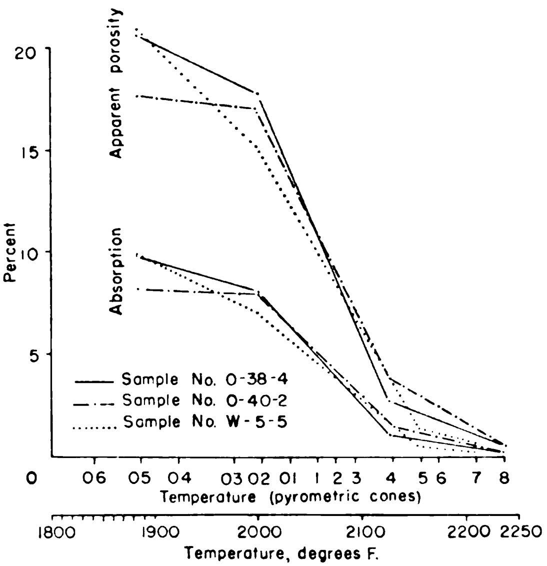


Fig. 4.—Graphs showing correlation of porosity-temperature and absorption-temperature curves for ball clay samples taken from different locations, but from stratigraphically equivalent beds.

of the ball clay than with other types. Within the lower range of firing temperatures, usually below cone 02, changes in size, absorption, porosity, and bulk specific gravity are rather small. At about cone 02 changes of these properites with increasing temperature is rather rapid until the clay approaches vitrification, commonly around cone 4. Above this temperature fired properties again change but little with increasing temperature, often leveling off completely for several cones increase in temperature after the absorption is reduced to about 1 percent. This is characteristic of clay having a long firing range and a long vitrification range. Changes of absorption and porosity with temperature increase are shown graphically in Figure 4. Similar changes in apparent and bulk specific gravities are shown in Figure 5. It will be noted that the apparent and bulk specific gravities approach the same value with increasing temperature.

Data on the ceramic properties of 10 Tennessee ball clays (Whitlatch, 1940) are given in Table 12 for convenience in making comparisons with the Kansas ball clays. Chemical analyses of nine of these clays are given in Table 9.

TABLE 11.—*Data on ceramic tests of Kansas ball clays*

Plastic and Dry Properties

Sample No.	Dry color	Water of plasticity, percent	Shrinkage water, percent	Pore water, percent	Volume shrinkage, percent	Calculated linear shrinkage, percent	Time required to slake 1" cube, minutes	Modulus/Rupture lbs. per sq. in.
C-27-5	light gray	29.6	14.3	15.3	26.5	8.2	11	340
C-27-13a (50% grog)	light gray	14.2	3.8	10.4	7.6	2.5		
El-12-4	gray	28.0	13.2	14.8	25.7	7.9	19	462
El-52-3	ivory	20.8	9.4	11.4	20.4	6.4	62	473
L-38-5	light gray	24.5	12.7	11.8	25.4	7.8	85	421
O-6-3	light gray	22.1	10.6	11.5	21.0	6.6	72	260
O-38-4	light gray	19.5	10.3	9.1	21.0	6.6	126	239
R-6-9	dark gray	26.7	14.3	12.4	27.6	8.5	170	349
R-6-11	gray	25.2	12.9	12.3	25.1	8.0	191	288
W-5-5	gray	24.0	12.1	11.8	24.0	7.4	80	461
W-5-A	gray	26.4	13.4	13.0	26.6	8.2		608
W-19-2***	gray	21.5	9.6	11.9	19.5	6.1	71	359
W-19-3	gray	32.3	19.4	12.8	38.0	11.3	42	776

Fired Properties

Sample No.	Fired to cone	Fired color	Volume shrinkage, percent	Calculated linear shrinkage, percent	Absorption, percent	Apparent porosity, percent	Apparent specific gravity	Bulk specific gravity	Hardness **	Best firing range (pyrometric cones)	Pyrometric cone equivalent
C-27-5	02	cream	26.2	9.6	3.4	7.9	2.50	2.30		07 to 8+	29-30
	5	cream	25.2	9.2	2.6	5.8	2.40	2.26			

C-27-13a	5	cream	6.5	2.2	7.0	14.0	2.29	2.00		05 to 14	
(50% grog)	8	cream	6.6	2.3	6.7	13.4	2.31	2.00			29-30
	11-12	gray cream	6.7	2.3	6.6	13.0	2.32	2.00			
El-12-4	05	cream	9.7	3.3	13.5	25.9	2.59	1.92	S	02 to 13	
	02	cream	15.5	5.7	10.2	21.3	2.66	2.09	S		above 30
	5	cream	20.7	7.4	4.8	10.7	2.46	2.20	S		
	8	cream	22.3	8.1	4.0	8.8	2.41	2.20	H		
	12	gray cream	24.7	9.0	2.2	5.2	2.43	2.30	H		
El-52-3	05	ivory	12.6	4.4	12.4	24.8	2.66	2.00	H		
	01	cream	22.3	8.1	5.1	11.2	2.49	2.21	H	05 to 12	
	5	cream	25.7	9.4	0.6	1.3	2.43	2.40	H		30
	9	dark cream	28.5	10.6	0.4	0.9	2.42	2.40	H		
	12	light gray		5.0	0.2				H		
L-38-5	02	cream	15.2	5.4	6.6	14.4	2.56	2.19	S	05 to 11	29-30
	4	cream	19.9	7.1	1.5	3.4	2.38	2.30	H		
	8	gray cream	16.1	5.7	0.6	1.4	2.24	2.21	H		
	11	gray cream	17.7	6.3	0.9				H		
O-6-3	03	ivory	16.3	5.8	7.9	16.9	2.56	2.13	H	05 to 8+	29-30
	5	cream	24.9	9.1	0.7	1.6	2.44	2.40	H		
O-38-4	05	ivory	12.5	4.4	10.0	20.8	2.64	2.09	S		
	02	cream	14.7	5.2	8.4	17.7	2.56	2.11	S	05 to 8+	
	4	cream	22.2	8.0	1.2	2.8	2.39	2.32	H		29-30
	8	cream	21.8	7.9	0.3	0.7	2.32	2.30	H		
R-6-9	03-04	cream	17.8	6.3	8.2	17.1	2.51	2.08	S	06 to 7	
	6	buff	23.4	8.5	2.7			2.20	H		
R-6-11	07	cream		0.8					S	07 (?) to 5	
	02	buff	17.1	6.1	5.1	11.3	2.49	2.21	H		
	4	tan	16.3	5.8	3.1	6.7	2.34	2.18	H		

TABLE 11.—*Dota on ceramic tests of Kansas ball clays, continued*

		Fired Properties								
Sample No.	Fired to cone	Fired color	Volume shrinkage, percent	Calculated linear shrinkage, percent	Absorption, percent	Apparent porosity percent	Apparent specific gravity	Bulk specific gravity	Hardness **	Best firing range (pyrometric cones)
W-5-5	05	cream	11.8	4.1	10.4	21.1	2.56	2.02	H	
	02	cream	16.3	5.8	7.1	15.2	2.55	2.16	H	05 to 6+
	5	cream	23.4	8.5	0.7	1.5	2.37	2.33	H	
	13-14	gray cream	1.7	0.6	9.5	17.1	2.17	1.80	H	
W-5-A	04	dark cream	13.3	4.7	8.2	17.3	2.56	2.12	H	04 to 5+
	5	cream	24.1	8.8	0.2	0.5	2.41	2.40	H	
W-19-2†	04	ivory	3.5	1.2	13.3	26.3	2.69	1.98	S	
	01	cream	7.6	2.6	10.4	21.2	2.60	2.05	S	4 to 12 +
	4	cream	9.6	3.3	8.9	18.6	2.57	2.09	H	
	7	cream	10.6	3.7	7.5	15.8	2.49	2.10	H	
	11	cream	12.4	4.3	5.8	12.8	2.51	2.19	H	
W-19-3	04	buff	20.9	7.5	3.2	7.4	2.46	2.28	S	05 to 7+
	3	dark cream		7.6	0.43				H	
	7	tan		7.6	0.22					

*Plus sign (+) indicates expansion.

** (S) indicates softer than steel; (H) indicates harder than steel.

†Sample W-19-2 is plastic fire clay, included here for reasons explained in the text.

TABLE 12.—*Ceramic properties of 10 Tennessee ball clays*
(Whitlach, 1940, pp. 348-353)

	Plastic and dry properties			Fired properties						
Sample Test no.	Original color	Water of plasticity, percent	Linear shrinkage, percent	Fired to cone no.	Color	Linear shrinkage, percent	Absorption, percent	Apparent porosity, percent	Hardness*	Best firing range, (cone numbers)
298	light gray	23.0	4.9	3	light cream	3.3	14.3	26.1	S	5 to 12—
				9	gray cream	6.6	2.1	4.8	H	
				12	light cream	8.0	0.0	0.0	H	
299	light gray	34.3	4.9	3	light cream	8.0	18.3	23.6	H	
				9	gray cream	14.4	1.1	2.5	H	1 to 12—
				12	gray cream	14.4	0.7	1.5	H	
301	brownish gray	34.6	6.6	3	light cream	9.9	10.8	20.9	S	
				9	gray cream	11.2	0.5	1.2	H	1 to 12—
				12	light gray	13.2	0.6	1.3	H	
302	med. gray with pink	34.3	6.6	3	cream white	8.0	13.3	25.6	H	
				9	cream-gray	13.2	3.1	7.2	H	3 to 12—
				12	med. cream	13.2	2.8	6.3	H	
304	light gray	33.5	6.6	3	cream white	9.9	10.4	20.9	H	
				9	light cream	13.2	2.0	4.8	H	1 to 12
				12	blue gray	13.2	0.0	0.0	H	
306	gray	28.1	4.9	3	cream white	4.9	12.7	24.1	H	
				9	light cream	9.9	5.1	11.1	H	1 to 12—
				12	light cream	9.9	3.2	6.8	H	
310	chocolate brown	36.2	9.9	3	cream	6.6	1.8	4.1	H	
				9	stone gray	9.9	0.0	0.0	H	1 to 12
				12	stone gray	9.9	0.0	0.0	H	

TABLE 12.—*Ceramic properties of 10 Tennessee ball clays, continued*
(Whitlach, 1940, pp. 348-353)

Sample Test no.	Original color	Water of plasticity, percent	Linear shrinkage, percent	Fired to cone no.	Color	Linear shrinkage, percent	Absorption, percent	Apparent porosity, percent	Hardness*	Best firing range range, (cone numbers)
311	grayish brown	36.6	9.9	3	gray cream	8.0	0.8	1.6	H	
				9	brown gray	8.0	0.6	1.4	H	1 to 12
				12	brown gray	9.9	0.5	1.0	H	
322	slate gray	35.2	6.6	3	cream	9.9	6.1	12.8	H	
				9	cream gray	11.2	2.3	3.1	H	1 to 12
				12	blue gray	11.2	0.0	0.0	H	
385	gray	32.4	8.0	3	gray-white	6.6	12.3	23.7	H	
				9	cream	11.2	4.5	9.8	H	
				12	cream	11.2	3.3	7.1	H	

*(H) indicates harder than steel; (S) softer than steel.

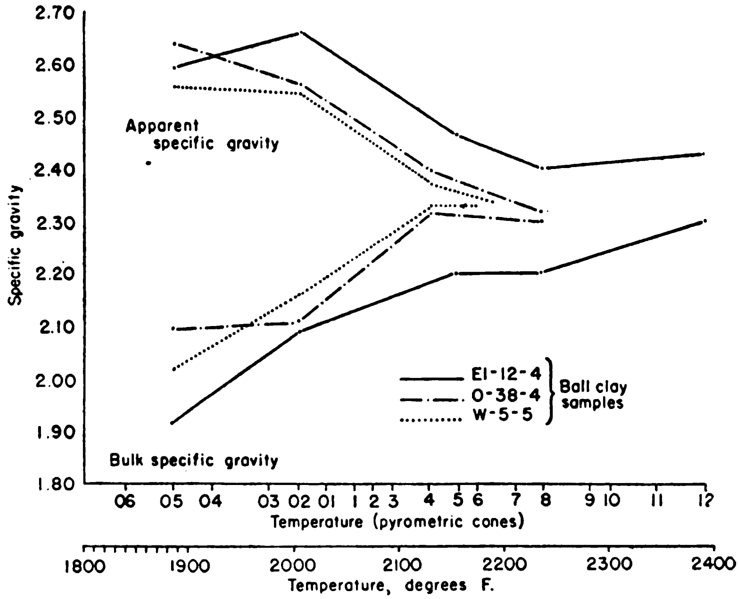


Fig. 5.—Graph showing change in apparent specific gravity and bulk specific gravity over the range of firing temperatures for typical ball clay samples.

The property of the Tennessee ball clays which differs most markedly from that of the Kansas clays is the water of plasticity. This is due in part to the greater percentage of organic matter present in many of the Tennessee clays, and in part to differences in personal judgment as to what constitutes the correct degree of plasticity. We used only enough tempering water to permit deformation of the plastic mass without cracking or checking. All other values are fairly comparable within the range of temperatures given, although the differences between individual clays are great for both the Tennessee and the Kansas clays.

Plastic Fire Clay (Exclusive of Ball Clay)

As explained on preceding pages, the distinction we make in this report between ball clay and nonball clay is an entirely arbitrary one. We excluded any plastic fire clay having alumina content below 25 percent, or an alumina to silica ratio exceeding 1:2.6, from the ball clay class. To avoid an unwieldy nomenclature we shall term the latter class of clay simply "plastic fire clay."

This use of the general term "plastic fire clay" to designate a specific class, and the name "ball clay" for another specific class of plastic fire clays is in accordance with common usage. As used here the specific class "plastic fire clay" also will include the so-called "wad" and "sagger" clays. Any plastic fire clay having an alumina content of 25 percent or more, or an alumina to silica ratio below 1:2.4, is classed, specifically, as a ball clay. A fire clay having a silica content higher than 70 percent and an alumina to silica ratio exceeding 1:3.5 is classed as siliceous fire clay. A fire clay having a silica content of 70 percent or less, and an alumina to silica ratio less than 1:4.0 is classed as a plastic fire clay (Table 4).

Many of the plastic fire clays having an alumina content below 25 percent have the physical properties of ball clays. In fact, a few excellent ball clays, well known to the ceramic trade, range in alumina content from 24 to 26 percent. It is obvious, therefore, that field identification of the intermediate grades is difficult and often impossible. The more siliceous of the plastic fire clays feel gritty between the teeth, and lack the talclike smoothness of the ball clays.

Plastic fire clay (hereafter used in the specific sense) is available in enormous tonnages in the Dakota formation of Kansas. Several beds as much as 20 feet in thickness have been found, and beds ranging in thickness from 5 to 10 feet are of very common occurrence.

Location and Occurrence of Samples Described

Eighteen plastic fire clay samples are described on the following pages. These samples were taken from locations having the following index numbers: Cloud County, C-12; Ellsworth County, El-29, El-38, and El-91; Ford County, F-1 and F-2; Hodgeman County, H-1; Lincoln County, L-6 and L-39; Washington County, W-1.

(C-12) A series of 15 pits were excavated at location C-12 in the steep north slope of the range of hills northwest of Miltonvale, Cloud County. Beds of clay similar to those sampled at C-12 were also sampled at locations C-2, C-5, C-6, C-7, C-8, C-9, C-13, C-14, C-15, and C-28, all within 1½ miles of C-12. A bed of clay of uniform quality occurring in the Janssen member ranging from 4 to 6 feet in thickness, and of considerable lateral extent, was sampled at locations C-35, C-43, C-44, and C-46. The distance from C-12 to these locations ranges from 5 to 8 miles to the west. Although large tonnages of good quality refractory clay are available in this area, the beds occurring within a distance of 1½ miles of C-12 are irregular in occurrence and thickness. The extent and thickness of the deposits should be disclosed by core-drilling prior to any large scale development of the clays.

Measured section of pits from which sample C-12-B (1 and 2) was taken, SE¼ sec. 11, T. 8 S., R. 2 W., Cloud County.

Bed No.		Thickness, in feet
	Soil and residual; contains fragments of Greenhorn limestone	2.5
	Graneros shale	
11.	Shale, clayey to silty, gray to dark gray with limonitic horizontal bands and some gypsum	9.7
10.	Hematite, limonite, yellow silt and sand and some gray shale in thin beds	1.7
	Total thickness of Graneros shale exposed	11.4
	Dakota formation	
	Janssen member	
9.	Silt, clayey, light gray, buff, and yellow, with limonite and siderite "shot" in upper half	2.1
8.	Clay, plastic, gray with slight yellow stain; contains fragments of lignite	3.9±
7.	Silt to very fine sand, gray to buff with some thin clay streaks	2.5±
6b.	Clay to silt, gray; contains lignite particles and a band of concretionary limonite near middle	1.9
6a.	Clay, silty to plastic, very dark gray; contains much lignite	1.0
5c.	Silt, gray to buff; contains scattered limonite concretions	13.0
5b.	Silt, clayey, yellow and red; contains siderite, limonite, and hematite "shot"	3.0—
5a.	Silt to fine sandstone, gray to yellow; contains limonite "shot" in upper half	5.0±
4.	Clay, slightly silty, gray with a considerable amount of yellow stain and yellowish-brown mottling and lignite particles near top and bottom	6.6±
3.	Silt to sandstone, light gray and yellow; contains lignite	0.8
B.	(Beds 1 and 2). Clay, slightly silty to fairly plastic, gray to light gray, with a slight amount of yellow stain. Lignite particles occur throughout. Jointing is vertical, and fracture conchoidal	17.2
	Total thickness of Janssen member exposed	57.0

Terra Cotta clay member		
01.	Clay, plastic to silty, gray, red, and brownish-red mottled	20.8
02.	Clay and hematite "shot"	0.4
03.	Clay, gray, and silt, yellow in alternating thin beds	2.3
	Total thickness of Terra Cotta member exposed	23.5

Although a total thickness of about 54 feet of beds is described in the above section as occurring above bed B, this constitutes the maximum thickness of overburden. All the beds described either crop out on the hill slope or are covered by a few inches of soil and weathered material. After removing a moderate depth of overburden, large tonnages of clay could be taken out by contouring the hills.

(El-14) Sample El-14-01 was taken from a series of pits excavated at location El-14 in the NW¼ sec. 25, T. 15 S., R. 7 W., about 1½ miles southeast of Carneiro, in Ellsworth County. This same bed of clay and associated beds were sampled at several locations in the vicinity of Carneiro. These locations include El-12 (W½ sec. 29, T. 15 S., R. 6 W.), El-13 (N½ sec. 5, T. 16 S., R. 6 W.), El-69 (SW¼ NW¼ sec. 30, T. 15 S., R. 6 W.), El-72 (SW¼ sec. 19, T. 15 S., R. 6 W.), and El-90 (SW¼ sec. 24, T. 15 S., R. 7 W.). In the Terra Cotta area, east of Carneiro, these same beds of clay were sampled at location TC-2 (SW¼ sec. 15, T. 15 S., R. 6 W.), TC-4 (NE¼ NE¼ sec. 14, T. 15 S., R. 6 W.), El-11 (SW¼ NW¼ sec. 36, T. 15 S., R. 6 W.), El-15 (NW¼ sec. 15, T. 15 S., R. 6 W.), and several others.

Bed 01 of location El-14 occurs in the lower part of the Terra Cotta clay member.

Beds 03 and 04, which overlay bed 01 at location El-14, are refractory light-firing clays. Bed 04 is described in the chapter on kaolin. Bed 05 is a pink- to buff-firing clay having unusually good working and firing characteristics. In other pits excavated a few hundred yards west of those described, these beds were much more siliceous, whereas in pits to the south only slight differences were noted, except that the thickness of the beds varied somewhat. Sample El-14-01, here described, is typical in its physical and chemical properties of other samples of the same bed taken in the Carneiro and Terra Cotta areas.

Beds 01, 03, 04, and 05 were combined to form a composite bed 16.5 feet in thickness. This bed (El-14-A) is a siliceous fire clay

Measured section of pits from which sample El-14-01 was taken, NW¼ sec. 25, T. 15 S., R. 7 W., Ellsworth County.

Bed No.		Thickness, in feet
	Dakota formation	
	Terra Cotta clay member	
	Soil, clay, and sandy residual	2.3±
05.	Clay, silty, light gray, with horizontal limonitic streaks, and some red mottling, and granular hematite toward top of bed	4.3
04.	Kaolin, very light gray to white, with some yellow joint stain (described under kaolin)	1.5--
03.	Clay, silty, lignitic, gray with some yellow stain	3.9
02.	Silt, clayey, lignitic, with some yellow stain	3.9
02.	Silt, clayey, lignitic, with some yellow streaks	0.5
01.	**Clay, fine-grained, plastic, gray to dark gray, thin-bedded with minute amounts of light-colored silt on bedding planes; contains some lignitic particles and a small amount of pyrite**	**6.9+**

firing to a cream color and having an absorption of 8.5 percent at cone 12. Beds 01, 03, and 04, similarly combined, comprise a bed (El-14-B) 12.3 feet in thickness. This composite bed is a plastic to siliceous fire clay which fires nearly white and has an absorption of 16.5 percent at cone 06. At cone 11 the fired color is cream and the absorption 6.3 percent. The P. C. E. is cone 29-30.

(El-29) Three groups of pits were excavated at location El-29. One group, consisting of a series of five pits, is given in the stratigraphic section below. The thickness and general appearance of the beds, as exposed in the three groups of pits, differ somewhat. However, the beds can be correlated readily.

In this general area similar beds occur at the same horizon in the Janssen clay member at locations El-27, El-73, El-74, El-78, El-79, El-80, El-82, El-85, and El-91. Both location El-73 and El-91 are described elsewhere in this report.

Although beds 1 and 2 contain enough iron to produce orange, red, and tan colors on firing to different temperatures, their flux content is rather low to judge from the firing behavior. The test bricks made from bed 1 clay had an absorption of 4.0 percent at cone 12, and those from the bed 2 clay an absorption of 9.2 percent at cone 13-14. The sample from bed 3 is a cream-firing siliceous fire clay having an absorption of 15.4 percent at cone 13-14. Beds 3 and 4 were combined to form a composite bed (El-29-B) having a total thickness of 15.0 to 17.0 feet. This bed is a very usable siliceous fire clay firing to a cream color and having an absorption of 10.1 percent at cone 12.

Measured section of pits from which sample El-29-4 was taken, near Cen. W½ sec. 23, T. 14 S., R. 7 S., Ellsworth County.

Bed No.			Thickness, in feet
	Dakota formation		
	Janssen clay member		
	Weathered slope to top of hill; contains some gray silt and fine-grained yellow sandstone		5.0
7b.	Sandstone, fine-grained, buff to yellow; contains thin clay streaks		1.7
7a.	Siltstone, gray with some yellow spots; contains worm holes or root cavities		1.7
	Total thickness of bed 7	3.4	
6.	Clay, plastic, lignitic, nearly black		0.5
5c.	Silt, clayey, friable, gray; contains root cavities filled with woody lignite and limonite		2.3
5b.	Sandstone to siltstone, yellow, buff, and light gray; contains root cavities filled with woody lignite and limonite		5.0
5a.	Silt to very fine sandstone, yellow, buff, and gray, resistant and evenly bedded		3.9
	Total thickness of bed 5	11.2	
4e.	**Clay, plastic, nearly black**		**1.7±**
4d.	**Clay, plastic to slightly silty, light gray with very little yellow stain; contains a few lignite particles**		**4.0±**
4c.	**Clay, very silty, gray with some yellow stain; contains root or stem cavities filled with limonitic clay**		**3.9±**
4b.	**Clay, silty, lignitic, dark gray, with some yellow stain toward bottom**		**2.0±**
4a.	**Clay, silty, gray with some yellow stain; contains a small amount of selenite**		**1.2±**
	Total thickness of bed 4	**12.8**	
3.	Clay, silty, lignitic, very dark gray, with some rusty yellow streaks; contains pyrite and selenite. Bottom of bed is very irregular, and has a churned appearance. (A siliceous fire clay)		2.2-4.2
2b.	Clay, silty, gray with some yellow streaks; contains a small amount of selenite		0.0-2.0
2c.	Clay, very silty, yellow and light gray, roughly banded, with limonite or siderite "shot" in upper part		5.0
	Total thickness of bed 2	5.0-7.0	
1.	Clay, fairly plastic, gray and yellow; contains limonite or siderite "shot" near center of bed		8.0
	Total thickness exposed in pits		45.1

(El-38) The pit excavated at location El-38 was in the NW¼ NW¼ sec. 15, T. 15 S., R. 9 W., Ellsworth County, and about 1 mile south-southwest of Janssen Station, for which the Janssen clay member of the Dakota formation was named (Plummer and Romary, 1942). The clay described at location El-38 occurs near the top of the Janssen clay member, and therefore near the top of the Dakota formation. Clay similar to beds 04 and 05, described below, is usually found at this horizon, although the thickness of the beds varies greatly. Beds of valuable fire clay occurring in the Janssen clay member were found in at least 40 other locations in Ellsworth County alone. All the valuable clays sampled in Ford, Hodgeman, Barton, Russell, and Republic Counties were found in this member.

In the Janssen area, west and southwest of Ellsworth, clays equal in quality and in some cases better than the El-38 clay were sampled at locations El-35, El-37, El-39, El-40, El-41, El-42, El-43, El-44, El-45, El-54, El-55, El-56, El-57, El-58, El-59, El-60, El-61, El-62, El-63, and others. The names of the owners, and section, township, and range of these locations are given in Table 26.

Measured section of pits from which samples El-38-04 and El-38-05 were taken, NW¼ NW¼ sec. 15, T. 16 S., R. 9 W., Ellsworth County.

Bed No.		Thickness, in feet
	Dakota formation	
	Terra Cotta clay member	
	Soil and weathered clay and silt	2.0+
06.	Clay, plastic, gray, yellow, red, and magenta mottled	1.5
05.	**Clay, thin-bedded, plastic, gray with some yellow and pinkish stain and minor amounts of irregular sand. The lower half of the bed is light gray with very little stain, but contains some clayey, fine, white sand**	5.0
04.	**Clay, thin-bedded, plastic, light gray with slight amount of yellow stain and isolated spots of yellow sand on bedding planes in upper two-thirds**	6.4
03.	Clay, plastic, gray to yellow, with very thin bands of yellow sandy clay	0.4-2.0
02.	Hematite, clayey to silty, dark red to purplish	0.3
01.	Silt to sandstone, gray, yellow, and lavender in lenticular thin beds alternating with gray and lavender clay	4.5+

The clay of beds 04 and 05 comes out in large, flat slabs which break out along bedding planes. Although very smooth to the touch the clay rattles when handled, as if quite hard. In this respect it resembles beds F-1-13 and F-1-14, previously described, and which occur at the same stratigraphic horizon. The El-38 clays, however, will eventually slake down in water, although more slowly than the majority of Dakota formation clays. Inasmuch as location El-38 is the farthest southwest of any sampled in the central area, and as it is intermediate in degree of induration between other Dakota clays and those of Ford County, there is some basis for the hypothesis that the degree of induration increases gradually toward the west or southwest. Clay beds totaling 29.0 feet in thickness, and firing to colors ranging from cream to red, underlie bed 01 of location El-38.

(El-91) Location El-91 is about 5 miles north and 2 miles east of Kanopolis, Ellsworth County. The beds described occur in the upper part of the Janssen clay member at the same horizon as those of location El-38, which were described in the preceding paragraphs.

Measured section of pits from which samples El-91-1 and El-91-2 were taken, NW¼ sec. 33, T. 14 S., R. 7 W., Ellsworth County.

Bed No.		Thickness, in feet
	Dakota formation	
	Janssen clay member	
	Soil and residual	1.0+
6.	Sandstone to silt, evenly thin-bedded, yellow and gray	2.0
5.	Silt to fine sandstone, clayey, gray	0.8
4.	Clay, silty, gray, and sandstone, fine yellow; evenly thin-bedded with some limonitic bands	1.8
3.	Clay, silty, gray, stained light yellow and pink	1.0
2.	**Clay, slightly silty, gray with slight yellow stain; contains particles of lignitized wood and leaf fossils; has pronounced conchoidal fracture. Beds of white kaolin occur 4.0 feet from the top and at the bottom of the bed**	**8.1**
1.	**Clay, slightly silty, dark gray with a considerable amount of yellow-orange stain on joints in middle of bed; contains a few selenite crystals, particles of lignitized wood, and leaf fossils; fracture is conchoidal; clay is massive when freshly excavated but weathers platy due to paper-thin streaks of fine silt**	**16.0+**

These clay beds are quite uniform and the overburden slight over an area of several acres. No differences were noted in samples taken a quarter of a mile north of the pits described. Auger holes put down by the U. S. Bureau of Mines revealed two parallel channel sandstone bodies which trend in a northwest-southeast direction and lie on either side of the clay beds sampled. Thus the beds are restricted to a rather narrow elongated belt in the local area. Viewed in the large, however, these beds are very extensive. Within a few miles of location El-91 beds very similar to El-91-1 and El-91-2 were sampled at the same horizon at locations El-29, El-73, El-78, El-83, and El-85.

(F-1) Samples F-1-13 and F-1-14 from location F-1 should be considered as the upper and lower halves of a single bed of clay. Separate samples were taken because of slight differences in physical appearance. Several samples of the Ford and Hodgeman County fire clays which have an alumina content sufficiently high to place them in the plastic fire clay or ball clay types are not in fact plastic except after prolonged grinding. In this respect they differ from most of the Kansas fire clays from the Dakota formation. Although the Ford and Hodgeman County clay here arbitrarily classed as plastic fire clay has a talclike texture and is extremely fine-grained, it slakes very slowly in water, and is obviously harder than the other clays of this type sampled in the central and north-central areas. Even when freshly excavated and slightly moist the clay rattles when handled. The fracture is sharply conchoidal. It is obvious that the clays of the Ford and Hodgeman County area have in this respect the characteristics of a "flint" clay, and probably should properly be classified as semiflint fire clays. Data on drying and firing substantiate the field observations.

In general the beds of the Dakota formation are more completely indurated in the southwest than they are in the central and north-central areas. This fact is especially evident in the siltstone which occurs at the top of the formation.

This same series of beds, with local differences, was found throughout the outcrop area of the Dakota formation in Ford and Hodgeman Counties.

Because these clays have the characteristics of a semiflint clay, bed F-1-13 is included with the plastic fire clays, although the alumina content is above 26 percent. Both beds 13 and 14 would have the physical characteristics of a plastic fire clay after prolonged weathering or thorough grinding with water in a ball mill; otherwise they have none of the characteristics of a ball clay other than that of chemical composition. This is not true, however, of

Measured section of pit from which samples F-1-13 and F-1-14 were taken, NW¼ SW¼ sec. 30, T. 25 S., R. 23 W., Ford County.

Bed No.		Thickness, in feet
	Dakota formation	
	Janssen clay member	
15.	Silt to silty clay, very light gray with thin yellow sandstone streaks; contains limonite-filled root molds	2.8
14.	**Clay, nearly white, smooth and fine-grained but hard; contains a few limonite-filled root cavities**	2.8
13.	**Clay. Upper 1.6 feet nearly white with almost no stain; lower 0.9 feet dark gray. Both parts smooth but hard like bed 14**	2.5
12.	Clay, gray, silty, with very slight yellow stain	1.8
11.	Sandstone, yellow, and silt, gray	0.8
	Total thickness	10.7

all the fire clays sampled in Ford and Hodgeman Counties. Beds sampled at other localities, although occurring in the same stratigraphic position, slake rapidly in water and are therefore not semiflint clays.

(H-1) The beds exposed at location H-1 comprise the thickest section measured in Hodgeman County. For the most part, beds of the Janssen clay member only are exposed in this county. The best exposures of the clay beds of the Dakota formation in Hodgeman County were found to occur along the valley edge and on the small tributaries of Sawlog Creek throughout its entire course in the county.

The light-firing clays of Hodgeman County consist of a few beds of good quality. The beds vary in thickness and quality to some extent, but are fairly persistent. The Ford County clay beds occur at the same horizon, and are nearly identical in quality.

In another series of pits which were excavated about 100 feet west of those in which the above section was measured, a total

Measured section of pits from which sample H-1-6 was taken, SE¼ SW¼ sec. 24, T. 22 S., R. 22 W., Hodgeman County.

Bed No.		Thickness, in feet
	Greenhorn limestone formation	
	Graneros shale formation	
14.	Clay shale, fissile, gray to dark gray with a few thin rust-colored sandstone beds near top	34.0

13.	Clay to silt, shaly, gray to dark gray; contains an abundance of selenite crystals		4.0
12.	Silt, shaly, and some clay shale, with a large amount of selenite. A 0.1 to 0.2 foot bed of kaolin occurs at the top. This bed occurs at the same horizon as bed H-3-4, described in the section on Graneros shale		3.6
Dakota formation			
	Janssen clay member		
11.	Silt to sandstone, gray, buff, and yellow; contains lignite particles		1.0
10.	Silt and silty clay, thin-bedded to platy, gray with some yellow; contains leaf fossils near top of bed		5.0
9.	Siltstone, resistant, gray with some yellow stain		1.7
8.	Clay, silty, platy with thin silt partings, gray with a slight amount of yellow		1.6
7.	Clay, very silty to fairly plastic, light gray with limonitic joint filling; contains some lignite		4.6
6c.	**Clay, fairly plastic, gray**		**1.8**
6b.	**Clay, plastic, nearly black**		**1.1**
6a.	**Clay, plastic, gray, with some lignite**		**2.5**
	Total thickness of bed 6	**5.4**	
5.	Clay, fairly plastic, yellow and light gray; contains hematite and limonite pellets and aggregates of small pellets		4.0
4.	Clay, very silty, lignitic, gray to rather dark gray with some yellow; contains a small amount of pyrite		4.7
	Total thickness of measured section		69.6

thickness of 11.7 feet of clay occurring below bed 4 was exposed. Bed 01, the lowermost bed of this series, is described with the buff- to red-firing clays.

Of the beds described above, beds 4, 6, and 10 only were sampled. Beds 4 and 10 fire to a light-buff color. Bed 6 is an ivory- to cream-firing clay.

(L-6) The clay samples described below were taken from a series of pits excavated at location L-6 about 4 miles south and 6 miles east of Barnard, or 7 miles north and 2 miles east of Beverly in Lincoln County. Five beds of cream- to buff-firing refractory clay, totaling 27.7 feet in thickness, were sampled at this location. Of these only bed 11 has a silica content low enough to permit its classification as a plastic fire clay. Beds 6 and 13 will be described in the following chapter on siliceous fire clay, and the section of the pits showing beds 1 to 9 will also be given.

Beyond the area including perhaps 10 acres adjacent to the pits the extent of this particular deposit of clays could not be deter-

Measured section of pits from which sample L-6-11 was taken, SE¼ sec. 1, T. 11 S., R. 6 W., Lincoln County.

Bed No.		Thickness, in feet
Dakota formation		
Terra Cotta clay member		
16.	Sandstone, massive, coarse, brown, resistant to friable. Bottom of bed, as exposed in pit, slanted at 45° angle. This is a channel sandstone, local in extent	3.0-6.0
15.	Clay, plastic, red with some gray and yellow mottling	3.8-6.8
14b.	Clay, light gray, with some red and yellow stain toward top	3.9
14a.	Clay, gray, pink and yellow, with thin sandstone at top	1.5
13.	Clay, plastic, gray, without stain, but with some small lenses of lignite (described in chapter on siliceous fire clay)	3.0
12.	Sandstone to silt, gray, soft, micaceous, lignitic	1.1-2.0
11.	**Clay: upper 3.5 feet plastic, light gray with slight yellow stain; lower 4.5 feet very tough, plastic, dark gray with no stain. Lignitized leaf fossils are abundant**	8.0
10.	Clay, slightly silty, pinkish gray, with abundance of lignitized leaf fossils	2.0
1-9.	Described in chapter on siliceous fire clay	34.4
	Total thickness	62.8-63.8

mined from outcrops. Similar clays were sampled at location L-8, 3 miles west and 1½ miles north, and at location O-1, 3½ miles east and 1 mile north of location L-6.

(W-1) The clay beds sampled at location W-1 were traced to the south and southeast as far as 3 miles. Samples of these beds were taken at locations W-52, W-53, and W-54, and also at location W-51 which is about a quarter of a mile northwest of W-1. Location W-1 is less than 5 miles west of the town of Washington, and less than a quarter of a mile north of highway U. S. 36.

Bed 4 of location W-1 has been used by the brick plant at Endicott, Nebraska, for the manufacture of buff face bricks (Pl. 4A) and beds 1 and 2 have been used to a considerable extent for pottery making in schools of this state. A combination of beds 1, 2, and 4 is more suitable for use in the manufacture of face bricks and other structural units than any one used alone. Bed 4 fires to a light color but matures at a higher temperature than most brick plants care to fire their kilns. Beds 1 and 2 mature at lower temperatures, but the fired color is considerably darker than that of bed 4. Bed 4 and the combination of beds 1, 2. and 4 (W-1-B) are discussed in this report under the heading siliceous fire clay.

Measured section of pits from which samples W-1-1 and W-1-2 were taken, SE¼ SE¼ sec.1, T. 3 S., R. 2 E., Washington County.

Bed No.		Thickness, in feet
	Dakota formation	
	Terra Cotta clay member	
	Soil and weathered clay	1.0±
5b.	Clay, plastic, light gray and red mottled	3.0
5a.	Clay, fairly plastic, light gray and yellow mottled	2.0
4.	Clay, rather silty, light gray	7.7-10.7
3.	Clay, plastic, light gray and yellow; probably local in extent	0.0-2.2
2.	**Clay, plastic, gray with slight yellow stain; contains lignite particles; has pronounced conchoidal fracture**	**4.7-5.5**
1.	**Clay, slightly silty, dark gray with very little stain; breaks out in thin lens-shaped "shells" when excavated**	**5.6**
	Sandstone; thickness not determined.	
	Total thickness measured	26.0

Mineralogic Properties

The mineral constituents of the Dakota formation plastic fire clay differ from the ball clay only in the proportion of finely divided quartz to clay minerals. That the plastic fire clay has a proportionately greater amount of quartz is obvious, inasmuch as the silica content is by definition higher in the plastic fire clay. The dominant clay mineral is kaolinite, or minerals of the kaolinite group, although some illite is present. In general the iron content of the plastic fire clay is lower than that of the ball clays. This probably means that the iron-bearing minerals, which are now present in the clay in the form of siderite, limonite, or hematite, and in a few cases, pyrite, were deposited in amounts proportionate to the clay minerals present in the sediments. This may be due to the fact that the iron minerals, especially the limonite and hematite, have a specific gravity and particle size more nearly similar to the clay minerals than to the finely divided quartz. Inasmuch as illite contains iron as a constituent of the molecule, greater percentages of illite would increase the total percentage of iron present in the clay.

Further details concerning the mineral constituents of the Dakota formation clays are given in the chapter on ball clays. With the exception noted above these details apply equally well to the plastic fire clays.

Chemical Properties

The limits of the silica and alumina content of plastic fire clays included in this report are discussed at the beginning of this chapter, and are outlined in Table 4. Silica may range from about 60 percent to a definite 70 percent. Alumina may range from a definite 25 percent to about 18 percent. The alumina to silica ratio of clays given in Table 13 ranges from 1:2.4 to 1:4.0. The percentage of iron oxide, calculated as Fe_2O_3, ranges from 0.5 to slightly more than 2.0 percent. The percentage of titanium dioxide ranges from a trace to amounts exceeding the percentage of iron oxide. Calcium and magnesium oxides and the alkalies are usually present in very small amounts. This fact is of primary importance in a refractory clay, inasmuch as the ingredients mentioned are active fluxes which will lower the fusion point (P. C. E.) of a clay if present in any considerable quantity.

A general discussion of the chemical properties of clay has already been given.

Ceramic and Other Physical Properties

In the routine ceramic tests it was possible to obtain much more uniform and consistent results with the plastic fire clays than with ball clays because of the more open texture of the plastic fire clays which largely is due to the fact that they contain a higher percentage of finely divided quartz or silt. Almost identical results can be obtained by adding various proportions of flint or silica flour to the fine-grained ball clays. It is for this reason that we did not adopt the common practice of testing ball clays by mixing them with equal portions of silica flour. Test bricks of ball clays made from a mixture are indistinguishable from those made from the plastic fire clays in appearance, in chemical analyses, and in ceramic tests.

Extremely close-textured, fine-grained clays are difficult to test because of defects which develop in drying due to a high shrinkage and to unequal rates of drying on the inside and the outside of the test bricks; also because of the defects which develop in firing due to the high shrinkage which results in cupping, warping, and cracking, and to the difficulty experienced in oxidizing the test brick on the inside, failure of which results in black-coring, swelling, and splitting. Most of these difficulties

Table 13.—*Chemical composition of Kansas plastic fire clays described in this report* (Analyses by Raymond Thompson and Russell Runnels)

	Constituents, percent								
Lab. No.	Silica (SiO_2)	Alumina (Al_2O_3)	Iron oxide (Fe_2O_3)	Titanium oxide (TiO_2)	Calcium oxide (CaO)	Magnesium oxide (MgO)	Potassium and sodium oxides (K_2O Na_2O)	Ignition loss	Total determined
C-12-B	68.56	17.39†	1.68	....	0.30	0.40	1.56	10.91	100.80
El-14-01	67.14	22.15	1.28	0.56	0.55	0.27	1.68	6.80	100.51
El-29-4	68.98	19.35	1.61	1.30	0.16	trace	1.25	6.70	99.35
El-38-04	68.70	21.05†	1.23	....	0.29	0.37	1.80	5.72	99.16
El-38-05	67.59	21.13	1.15	0.55	0.66	0.32	1.88	5.81	99.09
El-91-1	62.58	22.02	2.18	0.29	0.61	0.44	1.38	10.88	100.38
El-91-2	62.99	22.30	1.74	1.49	0.73	0.71	1.70	8.23	99.89
*F-1-13	57.48	27.03	1.70	0.30	0.79	1.02	2.71	7.61	99.41
F-1-14	62.16	22.71	1.64	1.10	0.64	1.80	2.20	7.09	99.34
F-2-2	66.57	21.75	1.00	1.01	0.63	0.61	2.87	5.16	99.60
H-1-6	63.07	23.91	1.61	2.46	0.39	0.30	1.62	7.75	101.11
L-6-11	68.97	19.96	0.59	0.48	0.72	1.04	....	5.54	97.30
L-39-1	68.40	20.60	1.11	0.70	0.75	0.90	1.50	6.00	99.96
L-39-2	65.91	22.91	0.73	0.35	0.93	0.85	0.20	8.16	100.04
L-39-3	67.04	22.43	0.65	0.33	0.83	1.06	0.76	6.86	99.13
L-39-A	66.75	22.26	0.79	0.45	0.87	0.92	0.66	7.30	100.00
W-1-1	67.20	18.70	2.20	1.40	0.70	1.60	1.00	7.10	99.90
W-1-2	60.95	24.09	2.54	0.33	0.65	1.17	1.76	8.44	99.93

*F-1-13 is a ball clay included in this table for reasons explained in the text.
†Includes titanium oxide.

can be avoided by extruding the test bars from a de-airing pug mill, drying in a humidity drier, and firing very slowly in a highly oxidizing atmosphere.

These difficulties, however, are seldom experienced in testing the more open-textured plastic fire clays. Data on ceramic tests of plastic fire clay are given in Table 14 and Figure 6.

The modulus of rupture (transverse strength) of the test bricks, fired to near vitrification, ranged from 1,300 to 4,000 pounds per square inch. Higher values would be obtained on test bricks which were extruded from a de-airing pug mill, and therefore free from the mechanical defects almost unavoidable in a hand-molded brick.

The Kansas plastic fire clays are the most generally useful class of clays found in the Dakota formation. They can be formed

TABLE 14.—*Data on ceramic tests of Kansas plastic fire clays*

Plastic and Dry Properties

Sample No.	Dry color	Water of plasticity, percent	Shrinkage water, percent	Pore water, percent	Volume shrinkage, percent	Calculated linear shrinkage, percent	Time required to slake 1" cube, minutes	Modulus/Rupture lbs. per sq. in.
C-12-B	light gray	18.7	8.8	9.9	18.3	5.8	90	565
El-14-01	dark gray	28.9	15.3	13.6	28.9	8.8	14	293
El-29-4	gray	20.0	8.0	12.0	16.3	5.2	37	328
El-38-04	light gray	22.7	11.2	11.5	22.6	7.0	50	325
El-38-05	light gray	24.2	11.3	12.9	22.3	6.9	99	326
El-91-1	dark gray	28.1	13.3	14.8	25.0	7.7	21	231
El-91-2	dark gray	22.2	9.3	12.9	19.9	6.4	19	425
F-1-13	light gray	23.8	7.3	16.5	12.7	4.1	1	60
F-1-14	nearly white	27.0	8.0	19.0	14.2	4.5	3	103
F-2-2	very light gray	25.7	11.9	13.8	24.3	7.5	5	352
H-1-6	gray	26.5	13.8	12.1	27.7	8.5	11	388
L-6-11	gray	24.7	13.8	10.9	26.6	8.2	44	405
L-39-1	light gray	20.6	9.1	11.5	18.5	5.8	20	441
L-39-2	gray	21.8	10.1	11.7	20.2	6.3	92	293
L-39-3	gray	19.7	8.2	11.5	16.7	5.3	44	277
L-39-A	gray	20.2	9.2	11.0	18.7	5.9		336
W-1-1	dark gray	23.5	12.0	11.5	24.2	7.5	28	340
W-1-2	gray	27.1	13.8	13.3	26.8	8.2	45	400

Fired Properties

Sample No.	Fired to cone	Fired color	Volume shrinkage, percent	Calculated linear shrinkage, percent	Absorption, percent	Apparent porosity, percent	Apparent specific gravity	Bulk specific gravity	Hardness†	Best firing range (pyrometric cone	Pyrometric cone equivalent
C-12-B	05	light cream	3.1	1.0	9.8	20.3	2.60	2.07	S		
	01	cream	4.8	1.6	7.7	16.2	2.51	2.10	S	05 to	
	4	dark cream	9.2	3.2	5.6	12.3	2.48	2.18	H	12	
	8	creamy buff	11.4	4.0	3.9	8.7	2.41	2.20	H		
	12	gray	10.1	3.5	3.2	7.0	2.37	2.20	H		
El-14-01	05	light cream	6.9	2.4	14.3	27.2	2.61	1.90	S	02 to	cone
	01	light cream	13.3	4.6	9.0	18.0	2.66	2.00	S	above	27
	5	cream	19.5	7.0	5.1	11.2	2.48	2.20	H	12	
	11	gray	17.3	6.1	3.6	7.5	2.27	2.10	H		
El-29-4	05	white	3.0	1.0	13.5	26.4	2.65	1.95	S		
	01	white	6.2	2.0	11.7	23.4	2.63	2.01	S	5 to	
	5	ivory	7.8	2.6	10.5	21.8	2.65	2.07	S	above	
	8	cream	7.6	2.6	10.3	21.2	2.63	2.07	S	14	
	11	cream	8.6	3.0	8.9	18.6	2.57	2.09	S		
	13-14	cream		3.5					H		
El-38-04	06	cream	1.8	0.6	13.2	25.1	2.54	1.90	H		
	01	cream	10.0	3.5	6.3	13.3	2.42	2.10	H	04 to	
	4	cream	13.3	4.7	3.4	7.5	2.38	2.20	H	8	
	8	buff	16.7	5.9	0.2	0.5	2.31	2.30	H		
El-38-05	03	cream	9.1	3.1	9.4	18.9	2.49	2.02	S	04 to	
	5	cream	17.2	6.1	4.7	10.4	2.46	2.20	H	above	
	8-9	cream	19.5	7.0	2.7	6.2	2.45	2.30	H	9	

Table 14.—*Dota on ceramic tests of Kansas plastic fire clays, continued*

Fired Properties											
Sample No.	Fired to cone	Fired color	Volume shrinkage, percent	Calculated linear shrinkage, percent	Absorption, percent	Apparent porosity, percent	Apparent specific gravity	Bulk specific gravity	Hardness†	Best firing range (pyrometric cone	Pyrometric cone equivalent
El-91-1	04-05	light buff	8.1	2.8	16.1	28.9	2.53	1.80	S		
	4	cream	9.9	3.4	15.1	27.2	2.47	1.80	S	10 to	cone
	9	cream	11.3	3.9	13.4	25.0	2.49	1.87	S	15	28-29
	11	cream	12.2	4.2	10.6			1.90	S		
	13-14	cream	17.4	6.2	8.6	17.1	2.41	2.00	H		
	16	brown	5.7	1.9	14.2	24.1	2.24	1.70	H		
El-91-2	04-05	light cream	3.7	1.2	12.4	23.5	2.48	1.90	S		
	01	light cream	5.1	1.7	11.7	23.0	2.54	1.96	S	8 to	cone
	4	light cream	5.3	1.8	11.2	21.9	2.51	1.96	S	15	28-29
	8	cream	5.3	1.8	10.4	20.5	2.48	1.97	S		
	13-14	cream	5.1	1.7	7.8	14.9	2.26	1.92	H		
	16	tan			10.9	20.4	2.35	1.87	H		
F-1-13	03	dark cream	*3.2+	1.1+	20.4	30.5	2.16	1.50	S		
	5	dark cream	0.2+	0.2+	15.0	23.2	2.02	1.55	S		
	9	ivory	0.3	0.1	13.9	22.0	2.02	1.58	S	cone	
	13-14	cream	3.9	1.3	14.5	23.3	2.08	1.60	S	14 to	
	16	buff gray		4.6	4.0	7.1	1.88	1.75	H	16	
F-1-14	04	buff	1.7	0.6	14.3	24.2	2.24	1.70	S		
	01	light buff	5.2	1.8	11.1	19.6	2.19	1.76	S		
	4	creamy buff	8.6	3.0	7.7	14.0	2.12	1.82	S	cone	
	8	creamy gray	8.1	2.8	8.0	14.5	2.12	1.81	S	12 to	

	12	creamy gray	4.4	1.5	10.3	18.0	2.12	1.74	S	15
	16	creamy gray		0.3	12.9	19.7	1.90	1.53	H	
F-2-2	05	creamy buff	10.9	3.8	6.9	14.6	2.48	2.12	H	06 to
	6	buff	17.4	6.2	2.5	5.6	2.43	2.29	H	above
	8	gray	14.7	5.2	2.8	6.1	2.37	2.22	H	8
H-1-6	04	ivory	11.4	4.0	9.7	20.3	2.62	2.09	H	05 to
	5	cream	14.8	5.2	5.8	12.7	2.51	2.19	H	above
	9	cream	16.0	5.7	3.7	8.0	2.39	2.20	H	11
	11	cream	17.7	6.3	1.4	3.1	2.31	2.24	H	
L-6-11	07	cream	7.0	2.4	12.0	23.7	2.58	1.97	S	
	01	cream	11.2	3.9	7.9	16.5	2.49	2.08	S	04 to
	4	cream	16.2	5.7	4.9	10.9	2.47	2.20	H	8
	8	dark cream	20.0	7.2	1.6	3.6	2.39	2.30	H	
L-39-1	02	buff	9.8	3.4	5.8	12.3	2.42	2.12	H	
	4	orange buff	10.8	3.7	5.5	11.8	2.44	2.15	H	05 (?)
	8	cream buff	12.5	4.4	4.4	9.7	2.44	2.20	H	to
	12	gray buff	10.3	3.7	4.8	10.2	2.38	2.14	H	8
L-39-2	02	ivory	4.7	1.6	13.7	25.9	2.55	1.89	S	9 to
	4	cream	8.4	2.9	11.8	23.5	2.62	2.00	S	above
	9	ivory	10.4	3.6	10.4	20.8	2.52	2.00	S	16
	12	cream	10.8	3.7	9.0	18.0	2.44	2.00	H	
	14-15	buff	15.1	5.3	6.1	12.8	2.38	2.08	H	
	16	tan	18.2	6.5	2.8	6.1	2.33	2.19	H	
L-39-3	02	cream	4.1	1.4	12.0	23.9	2.62	1.99	S	cone 9
	4	cream	6.2	2.1	11.0	22.1	2.57	2.00	S	to above
	9	cream	7.0	2.4	10.7	21.3	2.54	2.00	S	16
	12	cream	7.2	2.5	9.7	19.5	2.50	2.01	S	
	14-15	buff	12.2	4.2	8.4	17.3	2.48	2.05	H	
	16	dark buff	16.3	5.2*	6.3	13.6	2.50	2.16	H	

TABLE 14.—*Dota on ceramic tests of Kansas plastic fire clays, continued*

L-39-A	04	ivory	4.0	1.4	12.8	25.5	2.69	2.00	S	4 to 14	
	2	cream	6.5	2.2	10.7	21.3	2.54	2.00	S		
	4	cream	7.0	2.4	10.3	20.7	2.53	2.01	S		
	9	cream	7.9	2.7	9.3	19.0	2.52	2.04	S		
	12	cream	9.7	3.3	7.4	15.6	2.49	2.10	H		
	14-15	buff		1.8	9.5	19.5	2.56	2.06	H		
	16	dark tan	2.1	0.7	9.8	19.0	2.40	1.94	H		
W-1-1	03	cream	4.8	1.6	12.7	24.9	2.61	1.96	S		
	5	cream	10.3	3.6	7.5	15.5	2.46	2.08	H	01 to above 13	cone 26
	8	buff	9.9	3.4	7.0	14.4	2.42	2.07	H		
	12-13	buff	11.5	4.0	5.5	11.5	2.37	2.10	H		
W-1-2	04	cream	9.8	3.4	11.8	23.6	2.62	2.00	H		
	5	cream	15.9	5.6	6.4	13.6	2.47	2.13	H	02 to 13	
	7	cream	16.8	6.0	7.0	15.2	2.56	2.17	H		
	9	cream	18.5	6.6	4.2	9.2	2.42	2.20	H		
	13-14	dark cream	10.9	3.8	6.4	12.8	2.29	2.00	H		

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*Plus sign (+) indicates expansion.

†(S) indicates softer than steel; (H) indicates harder than steel.

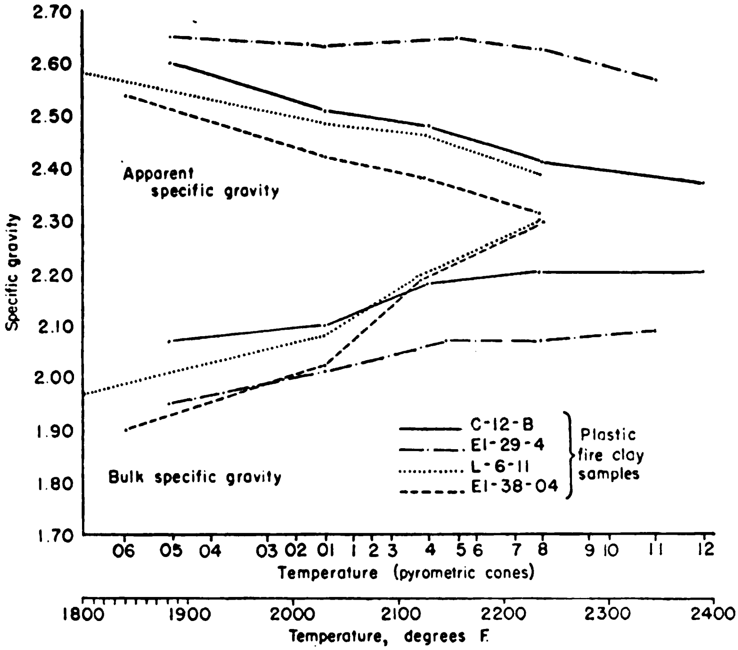

FIG. 6.—Graph showing changes in apparent specific gravity and bulk specific gravity over the range of firing temperatures for typical plastic fire-clay samples.

by any of the methods commonly employed in producing ceramic ware, including casting, throwing, jiggering, dry-pressing, and stiff-mud extrusion. Both in the laboratory and in commercial use they create no serious drying problems, although in many cases the drying shrinkage is relatively high in comparison to that of shales or flint clays.

The firing range of the plastic fire clays ranges from cone 06 to cone 8 for those vitrifying at low temperatures and to cone 16 and higher for those vitrifying at high temperatures. Tests conducted in a crucible furnace equipped with a muffle indicate that some of the clays must be fired to cone 23 or higher to be completely vitrified. Most of the clays can be fired to at least 4 cones above the minimum temperature of vitrification, and some of the clays have a vitrification range extending over about 8 cones of firing, or 250° F.

The clays which fire hard enough at cone 06 to cone 01 to withstand outdoor temperature and moisture changes are suitable for use in the manufacture of light-colored face brick, structural tile, and wall tile by the producer who wishes to keep the maximum temperature of his kilns within this range. The more open-burning, or siliceous clays would, of course, have to be fired to higher temperatures to obtain the same quality of product. For ware which must be vitrified, or nearly vitrified, such as stoneware (including chemical stoneware, common stoneware utensils, dinnerware, and art pottery) and floor tile, clays which can be fired to temperatures as low as cone 3 or 4 can be selected. Many, however, vitrify between cones 4 and 12, and others vitrify at temperatures too high to be used economically for such purposes.

Any of the clays are suitable for use in refractories. The ones selected for use will depend upon the manufacturing procedure preferred, and the use for which the refractory is intended. The P. C. E. of the clays sampled varies slightly, the majority ranging from cone 27 to cone 30. The more plastic and close-textured clays usually require a higher percentage of grog than the more siliceous open-firing clays. The use of more than one clay, and possibly a combination of types will in many cases prove more satisfactory than the use of one clay only.

Several of the clays tested have been used in the laboratory, and have stood up well under temperatures which caused deformation of the test kiln, intended for 2,500° F. use. One of the samples used as a pedestal in a crucible furnace, has withstood several cycles of heating and cooling in which temperatures as high as 2,800° F. have been reached. The flame impinged directly upon the brick, and the surface temperature probably was above 3,000° at the maximum.

The clay from beds El-38-04, El-38-05, El-69-2, and C-27-13 has been used in the manufacture of kiln furniture which proved very satisfactory in kilns firing roofing tile and insulating refractories. This same clay was also used in the manufacture of glazed structural tile blocks, and in wall tile. Both one-fire glazes applied by spraying and salt glazing were used.

Glazing tests have been made in the laboratory on several of the clays. We have had no difficulty in obtaining a good glaze on any of the clays tested. With proper care in the selection of a glaze low temperature (cone 01 to 02) glazes on a soft-fired body (absorption 10 to 12 percent) have proven very satisfactory. Glazes maturing at intermediate temperatures (cone 02 to 4) require a somewhat harder fired body, whereas the more durable higher temperature glazes (cone 4 to 12) must be used on a nearly vitrified body to prevent dunting and shivering while the ware is cooling in the kiln, or within 24 hours after its removal. The glazes we have used, including a wide range in types, have been under sufficiently high compression to produce fractures in bodies having an absorption above approximately 3 percent. This is especially true of the clays having a relatively high silica content.

Siliceous Fire Clay

A siliceous fire clay, as defined in this report, is one which has a silica content of at least 70 percent. Those having a silica content exceeding 80 percent are classed as highly siliceous fire clays, and are described under that heading. The basis for the clay classification used has been discussed previously. It is obvious that there is no sharp line of demarcation between the various types. From the standpoint of practical use no difference exists between a clay containing 69 percent silica and another containing 71 percent.

The siliceous fire clay is quantitatively the most important class of light-firing clays found in the Dakota formation in Kansas. Beds of considerable thickness are quite common, and laterally they are more uniform than the less siliceous types.

Location and Occurrence of Samples Described

Twenty-two clay samples selected to represent the siliceous fire-clay type described on the following pages include the following locations: Cloud County, C-29 and C-43; Ellsworth County, El-2, El-21, El-60, El-78, El-85, and TC-2; Ford County, F-3; Lincoln County, L-6, L-10, and L-39; Ottawa county, O-4; Washington County, W-1 (Pl. 1).

(C-29) Location C-29 is 1.5 miles south and 0.5 miles west of Miltonvale, Cloud County. Locations C-30 and C-48 are less than 0.75 mile distant, and for the most part include the same beds as those exposed at C-29. The clay beds exposed in the pits excavated at locations C-4, C-16, C-24, and C-28 also occur at approximately the same stratigraphic position, and are very similar in appearance.

Although bed 3 only was sampled at location C-29, probably bed 1 would fire to a dark-buff color, and bed 4 to a red. Samples

Measured section of pits from which sample C-29-3 was taken, NW¼ sec. 31, T. 8 S., R. 1 W., Cloud County.

Bed No.		Thickness, in feet
	Dakota formation	
	Terra Cotta clay member	
	Soil and weathered clay	0.8
4.	Clay, rather silty, gray and red mottled; contains hematite and limonite pellets, and large irregular masses of nearly pure hematite in lower half	9.6
3.	**Clay, rather silty, gray with slight yellow stain; contains fragments of lignite and lignitized leaf fossils**	**5.5**
2.	Sandstone, friable, lignitic, fine-grained, gray to yellow; contains small lenses of clay and silt	5.3
1.	Clay, silty, light gray with a considerable amount of yellow stain	14.8
	Total thickness measured	36.0

of similar beds taken at adjacent locations proved to be very workable clays which behaved well in firing.

(C-43) Bed 4 of location C-43 is the uppermost clay bed found in the Dakota formation, and is probably the most persistent. This same bed was also sampled at locations C-34, C-35, C-41, C-44, and C-46, all within an area of about 6 square miles. Within this area the clay beds are remarkably uniform in thickness, appearance, and ceramic properties.

The stratigraphic equivalent of bed C-43-4 was sampled in this area at six other locations, mentioned above. The quality of the

Measured section of pits from which sample C-43-4 was taken, NE¼ NW¼ and NW¼ NE¼ sec. 15, T. 8 S., R. 3 W., Cloud County.

Bed No.			Thickness, in feet
	Dakota formation		
	Janssen clay member		
	Partially covered slope to Dakota-Graneros contact		13.0
5b.	Silt to fine sandstone, thin-bedded, yellow to gray		3.5
5a.	Silt to very fine sandstone, massive, gray, horizontal bands of concretionary limonite and worm holes or root cavities		5.4
	Total thickness of bed 5	8.9	
4b.	**Clay, slightly silty, gray to dark gray with some yellow stain**		**3.0**
4a.	**Clay, plastic, light gray, some limonite-filled root cavities and some yellow stain**		**2.6**
	Thickness of bed 4	5.6	

3.	Clay, fairly plastic, gray with a considerable amount of yellow stain	13.3
2.	Clay, plastic, gray, slight amount of fine sand on bedding planes	2.9
	Total thickness measured	48.1

clay at C-43 is about average. At location C-44, 1 mile north of C-43, the clay was more silty, but fired to a much lighter color.

Bed 2 of location C-43 is a buff-firing clay. Bed 3 was not sampled but its equivalent at other locations fired to a red color.

The sandstone above bed 03 (bed 02) covers a relatively small area, so that several acres of clay could be excavated by removing a thin overburden.

(E-21) A total of 18 pits was excavated at location El-21. These were distributed in groups of 2 to 4 pits over an area of several acres east of the Independent Salt Company mine, Kanopolis. Only the north series of pits is described in the section given below. The clay beds found in the other groups of pits are nearly identical to those described, and are stratigraphically equivalent.

Measured section of pits from which sample El-21-9 was taken, Cen. S½ sec. 20, T.15 S., R. 7 W., Ellsworth County.

Bed No.		Thickness, in feet
	Dakota formation	
	Terra Cotta clay member	
	Soil and residual clay	
10.	Clay, very silty, light gray, mottled red, lavender, and yellow; contains small pellets of limonite and hematite	10.1
9.	**Clay, silty, gray with very little stain; contains a few thin short lenses of yellow to buff sandy clay and lignitized leaf fossils**	**8.9**
8.	Clay, silty, gray with some yellow stain; almost identical to bed 9 with exception of yellow stain	7.5
	Total thickness of section measured	27.3

Only bed 9 was sampled from this group of pits. Beds equivalent to bed 8 fired to a buff color, and those equivalent to bed 10 are red firing.

Location El-20, consisting of six groups of pits to the south and southeast of El-21, forms a continuous series with El-21. The upper beds sampled at location El-20 are equivalent to the beds sampled at El-21. Location El-20 will be described under highly siliceous fire clay.

(El-60) Groups of pits were excavated at five locations in sec. 19, T. 15 S., R. 9 W., 6 miles east of Ellsworth. These include El-45, El-57, El-59, El-60, and El-61. The clay and silt beds of the Janssen clay member, as exposed in this area, are unusually lignitic. A bed of fairly pure lignite was found near the Cen. E. line sec. 24, the clay beds in the upper part of the Janssen clay member are and also near the Cen. E½ sec. 19 (Whitla, 1940). In this area rather silty, but several beds that were sampled have an unusually low iron content, and their fired color is nearly white.

Samples El-60-6 and El-60-13 were taken from the same beds as exposed in two series of pits about 100 yards apart.

Measured section of pits from which samples El-60-6 and El-60-C were taken, SE¼ SW¼ sec. 19, T. 15 S., R. 9 W., Ellsworth County.

Bed No.			Thickness, feet
	Dakota formation		
	Janssen clay member		
9b.	Siltstone, clayey, thin-bedded, gray to yellow		2.2
9a.	Siltstone, massive, gray and yellow; contains root cavities		1.3
	Total thickness of bed 9	3.5	
***8c.**	**Clay, silty, with much limonite in thin bands**		**1.5**
***8b.**	**Clay, plastic, dark gray with some yellow stain**		**1.0**
***8a.**	**Clay, hard, smooth, nearly black**		**0.4**
	Total thickness of bed 8	**2.9**	
***7b.**	**Clay, rather silty, gray with some yellow streaks and leaf fossils**		**3.2**
***7a.**	**Clay, very silty, dark gray with some yellow streaks**		**3.8**
	Total thickness of bed 7	**7.0**	
***6.**	**Clay, apparently very silty, very light gray with some yellow joint stain; breaks out with pronounced conchoidal fracture. A trace of kaolin occurs at top of bed**		**4.1**
***5c.**	**Silt, lignitic, nearly black**		**0.8**
***5b.**	**Clay, plastic, mealy, gray**		**0.6**
***5a.**	**Silt, clayey, lignitic, dark gray**		**2.0**
	Total thickness of bed 5	**3.4**	
4b.	Clay, plastic, very light gray to gray with bright yellow and orange joint stain; contains limonite pellets		7.4
4a.	Clay very plastic, dark gray with some yellow joint stain		2.3
	Total thickness of bed 4	9.7	
3.	Siltstone, clayey, gray to yellow		1.0
	Total thickness measured		31.6

*Beds 5, 6, 7, and 8 were combinned as bed C (El-60-C), having a total thickness of 17.4 feet.

Measured section of pits from which sample El-60-13 was taken, SE¼ SW¼ sec. 19, T. 15 S., R. 9 W., Ellsworth County.

Bed No.		Thickness, feet
Dakota formation		
Janssen clay member		
16.	Siltstone, gray to light yellow; contains root cavities	1.3
*15b.	Clay, silty, thin-bedded, gray with thin limonitic streaks	4.7
*15a.	Clay, silty, dark gray	3.0
	Total thickness of bed 15	7.7
*14.	Clay, very silty, lignitic, dark gray with irregular kaolin streak at bottom	1.3-3.0
***13.**	**Clay, silty, gray with slight amount of yellow joint stain; has pronounced conchoidal fracture**	**4.3**
12.	Silt, clayey, lignitic, dark gray to black	1.2
*11.	Clay, plastic, light gray with some yellow stain	4.5
	Total thickness of section measured	20.3-22.0

*Beds 11, 13, 14, and 15 were combined as bed D (El-60-D).

In these two groups of pits 9 beds were sampled. Bed 4 has a high shrinkage on drying and firing, and fires to colors ranging from light orange to buff. Bed 5 is a cream- to buff-firing refractory clay. Bed 7 is an open-firing refractory clay which fires to colors ranging from ivory to cream. Bed 8 is a cream- to buff-firing fire clay. Bed 14 is a white- to cream-firing refractory clay. The fired color of samples 6 and 13 is nearly white. A total thickness of 17.4 to 19.5 feet of siliceous but cream- to buff-firing refractory clay is available at this location (beds El-60-C and El-60-D). These clays stand up well in use at temperatures not far below their P. C. E., or temperature of deformation, which ranges from cone 26 to cone 30. Beds 6 and 13 have an absorption of about 14 percent at cone 18.

The slope of the hill flattens out, or forms a bench above beds 9 or 16. Thus it would be possible to remove a considerable tonnage of clay under a moderate thickness of overburden by contouring the hillsides.

(El-78) The clay beds sampled at location El-78 and at El-60 occur at the same stratigraphic position and are very similar lithologically, being unusually silty and containing a considerable amount of lignite and carbonaceous material. Some of the beds vary laterally from lignitic clay to clayey lignite. The clay at several locations in the vicinity of El-78 also has the same lithological characteristics. These include El-73, El-74, El-91, and El-92.

Measured section of pits from which sample El-78-3 was taken, SE¼ NE¼ sec. 30, T. 14 S., R. 7 W., Ellsworth County.

Bed No.		Thickness, feet
	Dakota formation	
	Janssen clay member	
5.	Silt, thin-bedded, gray and buff	2.5
4.	Clay, silty, thin-bedded, gray to buff with some yellow	5.0
3.	**Clay, silty, lignitic, gray to dark gray, with some thin horizontal yellow bands and limonite on vertical joints and some paper-thin inter-beddings of white silt. A lens of gray to buff fine-grained sandstone to silt occurs in the lower part of the bed**	**19.2-25.6**
2.	Clay, silty to slightly silty, gray, with very slight yellow stain; contains a few yellow sandy streaks with concretionary limonite and paper-thin interbeddings of white sand or silt	10.5
1.	Sandstone, fine-grained, lignitic, nearly white with some yellow streaks	3.0
	Total thickness of section measured	46.6

The silt to sandstone lens which occurs in bed 3 has a maximum thickness of 6.4 feet, but a lateral extent of only 72 feet from east to west. A similar short lens occurs at the same stratigraphic position about 1 mile northwest of location El-78. In both cases the exposed cross-section of the lens is concave on the bottom and level on top. It is probable that these coarse sediments were deposited in the depressions of an irregular clay surface. At the point of maximum thickness of the sand and silt lens a thickness of 14.7 feet of bed 3 could be removed before encountering the lens. To judge from surface outcrops, the lens is completely absent over a considerable area, in which case the total available thickness of bed 3 is 25.6 feet.

Bed 2 at this location fires to dark buff, and bed 5 is red-firing. Beds 2 and 3 combined as one bed produce a buff-firing brick.

(El-85) The clays sampled at location El-85 correlate stratigraphically with those sampled at locations El-78 and El-91 which were discussed on preceding pages. The physical and chemical properties of the El-85 clays are intermediate in character between those of location El-78 and those of El-91. Location El-85 is approximately 3 miles southeast of El-91, and 3 miles north and 1.75 miles west of Carneiro, Ellsworth County.

Measured section of pits from which samples El-85-3 and El-85-4 were taken, sec. 2, T. 15 S., R. 7 W., Ellsworth County.

Bed No.		Thickness, feet
	Dakota formation	
	Janssen clay member	
	Silt and sand, weathered, and soil	1.7
5.	Silt to fine-grained sandstone, thin-bedded, buff, gray, and yellow, with limonitic breaks	3.3
4c.	**Clay, silty, lignitic, gray with some yellow stain**	**1.6**
4b.	**Clay, fairly plastic, gray with slight yellow stain; contains a small amount of limonite**	**1.5**
4a.	**Clay, rather silty, with pronounced conchoidal fracture, gray with slight yellow stain; contains a small amount of lignite and some very small selenite crystals**	**4.5**
	Total thickness of bed 4 7.6	
3.	**Clay, rather silty with pronounced conchoidal fracture, gray to dark gray with some yellow stain; small selenite crystals on vertical and oblique joints; contains some fragments of lignite**	**5.9**
2.	Clay, silty, gray with considerable amount of yellow joint stain; contains a small amount of pyrite	2.8
1.	Clay, slightly silty to plastic, gray with slight yellow stain; contains some selenite	6.3
	Total thickness of section measured	27.6

The hill rises rather steeply above the top of bed 5 for about 18 feet where it levels off abruptly. If this deposit of clay were to be developed extensively it would be necessary to remove an overburden averaging at least 20 feet in thickness. A considerable tonnage of clay could be removed, however, by contouring along the hill.

Careful test drilling would be necessary at this location to determine the exact tonnage available, inasmuch as the clay beds differ radically in appearance at an outcrop 0.25 mile northeast, and at another 0.5 mile north.

A combination of beds 1, 2, 3 and 4 (El-85-A), having a total thickness of 22.6 feet, fired to a cream color at cone 12, and had an absorption of 6.7 percent at that temperature. A combination of beds 3 and 4 (El-85-C), having a total thickness of 13.5 feet, also fired to a cream color at cone 12, but had an absorption of 10.9 percent.

(F-3) All of the locations sampled in Ford County are in a small area 4.5 to 7.5 miles north of Wright. All but location F-7 are less than 1 mile from highway U. S. 283. F-3 is about 0.25 mile north of F-1 and 0.75 mile northeast of F-2. All beds sampled in Ford County occur in the Janssen clay member, and the most valuable clays occur in the upper part of the Janssen.

Measured section of pit from which samples F-3-2 and F-3-A were taken, SW¼ SW¼ sec. 19, T. 25 S., R. 23 W., Ford County.

Bed No.		Thickness, feet
	Dakota formation	
	Janssen clay member	
4.	Silt to fine-grained sandstone, thin-bedded, yellow to reddish brown; contains small pellets of limonite and hematite	1.5
3.	Clay, hard but smooth, with some irregular yellow silty streaks	1.0
***2.**	**Clay, smooth but hard, very light gray to white; some limonite filling in root cavities**	**5.4**
***1.**	**Clay, smooth but very hard, dark gray, lignitic**	**1.4**
	Total thickness of section measured	9.8

*Bed F-3-A is a combination of beds 1 and 2.

The bottom of bed 1 was not reached in the pit. It is probable that more usable clay would be found below. The overburden at this location is quite thin over a considerable area. The pit from which sample F-3-2 was taken is less than 0.25 mile east of highway U. S. 283.

(L-6) Bed 11 (sample L-6-11) of location L-6 is a plastic fire clay. Further details are given in the paragraphs describing location L-6 under plastic fire clay.

Measured section of pits from which samples L-6-6 and L-6-13 were taken, SE¼ sec. 1, T. 11 S., R. 6 W., Lincoln County.

Bed No.		Thickness, feet
	Dakota formation	
	Terra Cotta clay member	
16.	Sandstone, massive, coarse-grained, brown	3.0-6.0
15.	Clay, plastic, red with some gray and yellow mottling	3.8-6.8
14.	Clay, gray to light gray with red and yellow mottling	5.4
13.	**Clay, plastic, gray with no stain; contains small lenses of lignite**	**3.0**
12.	Sandstone to silt, friable, micaceous, lignitic, gray	1.1-2.0
11.	Clay, plastic, gray to dark gray with slight yellow stain (plastic fire clay)	8.0
10.	Clay, lignitic, slightly silty, pinkish gray	2.0

9.	Clay, as above, but contains thin lenses of concretionary yellow sandstone	1.0
8.	Clay, gray, and sandstone, yellow in alternating thin beds	4.5
7.	Sandstone, massive, cream to yellow, with small lens of black clay	11.3
6d.	**Clay, plastic, dark gray**	**0.7**
6c.	**Clay, silty, light gray**	**0.7**
6b.	**Clay, plastic, light gray with some yellow in vertical joints**	**4.8**
6a.	**Clay, plastic, gray to dark gray with some yellow stain on joints; contains lignite fragments**	**2.0**
	Total thickness of bed 6	8.2
5.	Clay, yellow, interbedded with lignite	1.3
4.	Clay, plastic, light gray with yellow stain	2.8
3.	Clay, lignitic, light gray with yellow in vertical and oblique joints	2.3
2.	Sandstone, yellow; contains concretionary limonite	0.5
1.	Clay, plastic, gray with some yellow joint stain	3.0
	Total thickness of section measured	62.8-63.8

Nine beds, totaling 40 feet in thickness, were sampled at this location. Of the 40 feet sampled a total thickness of 34.7 feet fired to colors ranging from ivory to dark buff. The beds sampled and their fired colors follow: bed 1, buff; bed 3, dark buff; bed 4, dark buff; bed 6, light buff; bed 10, dark buff; bed 11, ivory to cream; bed 13, ivory to cream; bed 14, buff; bed 15, red.

(L-10) Two series of pits were excavated at location L-10. Two pits only are included in the measured section given in detail below. These were located on the lower slope of a hill which was roughly benched at the top of bed 03, so that over an area of several acres beds 01 and 02 are covered with an overburden of moderate thickness. Above the bench formed by this sandstone (bed 03) the hill rises steeply for about 26 feet. The clay beds sampled in this interval are mostly red-firing.

Bed 02 is a cream- to buff-firing clay. For many uses it would be desirable to combine beds 01 and 02 into one bed having a total thickness of 21.9 feet. This combination fires to colors ranging from cream to light buff, and on the whole produces a more workable clay than either bed used alone.

Other clay locations in the vicinity of L-10 are L-9, L-11, L-12, and L-13.

Measured section of pits from which sample L-10-01 was taken, NW¼ NW¼ sec. 10, T. 13 S., R. 7 W., Lincoln County.

Bed No.		Thickness, feet
	Dakota formation	
	Terra Cotta clay member	
03.	Sandstone, yellow to buff	1.0
02.	Clay, mostly plastic, gray with a small amount of yellow to orange stain in upper one-half	9.5
01.	**Clay, silty, gray to light gray; contains lignite and some pyrite in bottom 1.0**	**12.4**
	Total thickness of section measured	22.9

(L-39) Location L-39 is one of the 19 locations mentioned in the discussion of L-38 (plastic fire clay) and R-6 (ball clay), which were sampled in the Hell Creek- Saline River area southwest of Sylvan Grove, Lincoln County, and north of Wilson, Ellsworth County. Locations sampled in the immediate vicinity of L-39 are L-40, L-41, L-42, R-10, R-11, and R-12. An abundance of light-firing refractory clay was found throughout this area.

Measured section of pits from which samples L-39-1, L-39-2, and L-39-3 were taken, SW¼ NW¼ sec. 18, T. 13 S., R. 10 W., Lincoln County.

Bed No.			Thickness, feet
	Dakota formation		
	Janssen clay member		
6.	Silt to fine sandstone, friable, light yellow		8.0
5.	Clay, silty, thin-bedded to shaley, gray, with bands of concretionary limonite		2.8
4.	Sandstone, fine-grained, massive, yellow to gray		1.8
***3.**	**Clay, silty to very silty, gray with slight yellow stain**		**4.5**
***2b.**	**Clay, plastic, gray with very little stain**		**5.3**
***2a.**	**Clay, plastic, dark gray to nearly black; contains some lignite**		**2.5**
	Total thickness of bed 2	**7.8**	
***1b.**	**Clay, silty, lignitic, pinkish gray with yellow bands**		**1.5**
***1a.**	**Clay, plastic, very light gray with streaks of lignitic silt**		**2.1**
	Total thickness of bed 1	**3.6**	
	Sandstone, cross-bedded, fine-grained, gray, cream and yellow		25.0
	Total thickness of section measured		55.5

*The clay from the bottom of bed 1 to the top of bed 3, totaling 15.9 feet in thickness, is bed A (L-39-A).

Bed 2 of this series is a plastic fire clay, but is discussed under this heading because it separates two siliceous fire clay beds (1 and 3). Samples taken from beds 1, 2, and 3 were combined in proportion to the thickness of the beds and tested (bed L-39-A). This combination is obviously less siliceous than either bed 1 or bed 3, but nevertheless falls into the siliceous fire-clay class.

Tonnages of clay adequate to supply the demands of a moderate-sized brick plant for many years are available in the immediate vicinity of L-39 under an overburden equal in thickness or thinner than that shown in the measured section.

(O-4) Location O-4 is 4 miles west of Delphos, Ottawa County, in rugged hills west of the Solomon River. A total thickness of more than 200 feet of beds was measured at this location, and on roadside exposures on Boyer's hill, 0.5 mile south. The small portion of the measured section which is given below, however, includes most of the higher-quality light-firing clay. A considerable thickness of red-firing clay was found at the level of the river flood plain and higher.

Owing to the irregularity of the surface and to local variations in beds, it is difficult to estimate the amount of clay which could be removed before running into a prohibitive thickness of overburden. It is probable, however, that only a moderate thickness of overburden covers several thousand tons of light-firing clay.

Measured section of pits from which sample O-4-16 was taken, NE¼ NW¼ sec. 14, T. 9 S., R. 5 W., Ottawa County.

Bed No.		Thickness, feet
	Dakota formation	
	Soil and hillside wash	1.6
17.	Clay, fairly plastic, gray with some red and yellow	1.6
***16.**	**Clay, slightly silty, gray, with some irregular yellow stain; contains fragments of lignitized wood; fracture is prominently conchoidal**	5.4
***15.**	**Clay, fairly plastic to slightly silty, gray with almost no stains; contains some lignite; fracture is prominently conchoidal**	6.7
***14.**	**Clay, slightly silty, gray with some yellow stains; contains small flinty concretions**	4.9
	Total thickness given	20.2

*Total thickness of beds 14, 15, and 16 was tested as one bed (O-4-C).

Beds 14 and 15 of location 0-4 are very similar to bed 16, with the exception that bed 16 fires to a slightly lighter color. Beds 14 and 15 are buff-firing, but a combination of all three beds, comprising a composite bed with a total thickness of 17.0 feet (bed O-4-C) fires to a cream color. Nearly identical results were obtained on duplicate tests made on this same combination of beds from samples taken from pits excavated about 0.25 mile northeast of those for which the measured section is given.

(TC-2) Location TC-2 is in east-central Ellsworth County. In place of the usual county initial before the index number of the location, which for Ellsworth County is "El," the initial "TC" is used, indicating the local area in the vicinity of Terra Cotta Station. This is the type area of the Terra Cotta clay member.

The first Dakota formation clay sampled by us was from the Terra Cotta area—from bed 10 of location TC-2. Clay was also sampled from some of the same beds at locations TC-1, TC-3, TC-4, El-2, and El-15, all in the immediate vicinity.

Measured section of pits from which sample TC-2-10 was taken, W½ SE¼ sec. 15, T. 15 S., R. 5 W., Ellsworth County.

Bed No.		Thickness, feet
	Dakota formation	
	Terra Cotta clay member	
15.	Sandstone, medium to coarse-grained, yellow to brown; a channel sandstone	30.0±
14-12.	Clay, mostly plastic, gray with red mottling	24.6±
11.	Sandstone, medium to fine-grained, buff to yellow	2.0-3.3
10.	**Clay, slightly silty, massive, gray with some yellow stain on joints; contains a few lignite fragments**	**6.3+**
9.	Clay, silty, lignitic, pinkish gray	1.2
8-4.	Clay, silty to plastic, mostly gray with red and yellow mottling; contains two thin beds of hard clayey siltstone	25.0±
3.	Clay, plastic, liight gray with some yellow stain	4.2±
2.	Clay, silty, lignitic, dark gray	1.0-1.5
1.	Clay, silty to very silty, light gray with some yellow stain (highly siliceous fire clay)	7.0+
	Total thickness of measured section	108.0±

The beds sampled at this location have been correlated with beds sampled at most of the locations in the Terra Cotta area. However, variations in thickness and character of the clay are common. Although the thickness of bed 10 is given as 6.3 feet, this is the minimum thickness measured. At two other places sampled, one about 200 yards southwest and the other about 0.25 mile northwest, the equivalent of bed 10 is 9.8 feet thick, is fine-grained, plastic, and contains more yellow stain. On the other hand, the maximum measured thickness of the overlying sandstone (bed 11) is 8.3 feet, but at the other two places mentioned is but 2.0 and 3.0 feet thick.

The beds described as occurring above bed 10 comprise the maximum thickness of overburden, which extends over but a very small area. A considerable tonnage of bed 10 clay could be mined by removing a moderate thickness of overburden, but to do so it would be necessary to follow the outcrop contour around a rather steep-sided hill.

Beds 12 to 14, when combined as one sample, fire to colors ranging from pink through buff to brown. Beds 4 to 9 fire to a light red at low temperatures and dark buff at higher temperatures. Bed 3 is a light buff-firing clay. Bed 1 is a nearly white-firing clay, and will be described separately with the clays of the highly siliceous fire clay class.

(W-1) Location W-1 is described in detail under plastic fire clay. Although the silica content of beds W-1-1 and W-1-2 is sufficiently low to permit their classification as plastic fire clays, a composite or combination of beds 1, 2, and 4 contains more than 70 percent silica, and is classed as a siliceous fire clay. This combination bed, which was given the laboratory number W-1-B, proved to be a more generally workable clay than any of the beds used alone, and has the added advantage of making available for use the entire thickness of 20.0 feet.

Bed 5 fires to a pink color at low temperatures and to a dark buff at higher temperatures. This bed would probably be used if a brick plant were located on the site.

The clay beds at location W-1 could be developed economically and conveniently. The overburden is thin over a large area, and laterally the beds are fairly uniform in character for a distance of 2 or 3 miles to the south and southeast. Transportation facilities would also be quite adequate. The clay outcrops on either side of highway U. S. 36 and although the railroad siding at Morrowville is 3.5 miles distant, the Burlington tracks are but 1.5 miles north of the location.

Measured section of pits from which samples W-1-4 and W-1-B were taken, SE¼ SE¼ sec. 1, T. 3 S., R. 2 E., Washington County.

Bed No.		Thickness, feet
	Dakota formation	
	Terra Cotta clay member	
	Soil and weathered clay	1.0
5.	Clay, mostly plastic, light gray with red and yellow mottling	5.0
***4.**	**Clay, slightly silty, light gray with a small amount of yellow stain; contains some lignite particles; fracture is prominently conchoidal**	**7.7-10.7**
3.	Clay, plastic, light gray and yellow; not continuous	0.0-2.2
***2.**	**Clay, plastic, lignitic, gray with slight yellow stain**	**4.7-5.5**
***1.**	**Clay, slightly silty, dark gray**	**5.6**
	Total thickness of section measured	26.0

*Combined as bed W-1-B; total thickness, 20.0 feet.

Mineralogic Properties

In the Kansas fire clays the silica content in excess of 47 percent is largely present in the form of finely-divided quartz, which varies from fine silt, most of which passes a 200-mesh screen, to colloidal material. It is possible to calculate the approximate percentages of kaolinite and quartz present in the clays from chemical analyses. A clay containing 75 percent silica and 17 percent alumina (as a constituent of the kaolinite molecule) contains 55 percent free silica, or uncombined quartz, and 43 percent kaolinite, which accounts for the remaining 20 percent of silica, 17 percent alumina, and 6 percent chemically combined water. Other constituents such as hematite, limonite, ilmenite, and rutile do not exceed 2 percent in the lighter-firing clays (McVay, 1942). The small percentages of illite found in many of the clays would cause this calculation to be slightly but not appreciably erroneous.

The physical properties of a siliceous fire clay containing 55 percent quartz and 43 percent kaolinite are nearly identical to those of a mixture composed of 50 percent pure ball clay and 50 percent potter's flint, or silica flour, and is recommended for use as such.

On the whole, the iron-containing minerals—hematite, limonite, and siderite—are somewhat less abundant in the siliceous fire clays than in the plastic fire clays and ball clays.

Chemical Properties

The chemical properties of the siliceous fire clays do not differ significently from the other types except in the range of percent of silica, which is arbitrarily fixed by definition as being between 70 and 80 percent. The alumina to silica ratio of the clays included in Table 15 ranges from 1:3.5 to 1:6.7. The minimum content of iron oxide present in any Dakota formation clay was found to be in the class of siliceous and highly siliceous fire clays.

TABLE 15.—*Chemical composition of Kansas siliceous fire clays described in this report* (Analyses by Raymond Thompson and Russell Runnels)

	Constituents, percent								
Lab. No.	Silica (SiO_2)	Alumina (Al_2O_3)	Iron oxide (Fe_2O_3)	Titanium oxide (TiO_2)	Calcium oxide (CaO)	Magnesium oxide (MgO)	Potassium and sodium oxides (K_2O Na_2O)	Ignition loss	Total determined
C-29-3	72.01	19.50†	1.15	....	0.18	0.24	2.32	5.01	100.41
C-43-4	72.18	19.58†	1.70	....	0.27	0.51	2.11	5.29	101.64
El-2-04	78.49	14.57†	0.97	....	0.37	0.45	2.45	3.67	100.97
El-21-9	71.64	19.46	0.36	1.15	1.06	0.88	1.93	3.84	100.32
El-60-6	71.80	19.12	0.88	1.30	0.18	0.16	0.82	6.05	100.31
El-60-13	72.38	18.55	0.75	1.33	0.21	0.14	0.78	6.33	100.47
El-78-3	75.18	11.79	1.26	1.89	0.11	0.35	1.74	7.46	99.78
El-85-3	70.34	16.63	0.46	1.15	0.42	1.11	2.57	7.62	100.30
El-85-4	72.46	16.58	1.31	0.45	0.49	0.73	2.52	6.12	100.66
F-3-2	70.06	17.80	1.31	1.00	0.96	1.55	1.48	5.29	99.46
L-6-6	70.00	16.77	1.58	1.71	0.64	1.26	2.15	6.03	100.14
L-6-13	71.03	19.22	0.69	0.72	0.55	0.49	0.18	6.71	99.59
L-10-01	71.60	18.15	1.35	1.00	0.50	1.00	1.10	5.30	100.00
O-4-16	72.24	17.51	1.56	0.53	0.96	0.73	....	5.50	98.03
O-4-C	71.98	17.15	1.55	0.98	0.68	0.58	....	5.44	98.36
TC-2-10	75.31	17.04	0.97	0.17	0.24	0.25	0.67	4.74	99.39
W-1-4	79.95	13.33	0.78	....	0.75	0.51	....	4.18	99.50
W-1-B	71.53	17.58	1.69	0.71	0.71	1.00	....	5.68	98.90

†Includes titanium oxide.

Ceramic and Other Physical Properties

The siliceous fire clays are very easily workable. They have sufficient plasticity to permit hand molding, stiff-mud extrusion, or throwing on the potter's wheel, but due to their moderately open texture can be dried wihout special precautions. The open texture also makes it possible to fire the clays rapidly without cracking, bloating, or black-coring. In general the siliceous fire clays vitrify at relatively high temperatures. This is a desirable feature in refractories, but in some cases entails prohibitive costs in the manufacture of structural products. Data on ceramic tests on clays sampled are given in Table 16.

The estimation of the best firing range is based on the assumption that at the minimum firing temperature the clay should have an absorption but slightly above 10 percent in order to withstand outdoor temperature and moisture changes in a moderately severe climate. As a matter of fact, building bricks having an absorption as high as 20 percent will in some cases stand up under freezing and thawing tests when saturated with water, whereas others having an absorption under 10 percent will fail. The differences are due to variations in the physical characteristics of the clays.

A. S. T. M. standards for clay building brick (Designation: C 62-41 T) are much less severe than the standard of 10 percent maximum absorption which we have used in this report. The A. S. M. T. standard specifies an average maximum absorption of 17 percent subjected to freezing and thawing under severe conditions (grade SW). For brick used in the face of a wall, but above ground, an average maximum of 22 percent absorption is specified (grade MW). Back-up brick, or any brick not exposed to the weather, (grade NW) do not have a maximum percentage of absorption specified. The A. S. T. M. further specifies, however, that bricks having an average water absorption of less than 8 percent after 24 hours immersion in cold water need not meet the specifications for saturation coefficient (78 percent for grade SW). Bricks having an absorption of 8 percent after 24 hours immersion in cold water, and a saturation coefficient of 78 percent, would have a total absorption of about 10 percent. We are of the opinion, therefore, that a maximum total absorption of 10 percent insures a sound brick under almost any conditions of use.

The upper limit of the firing range is, of course, the highest temperature at which the clay can be fired without deforming or bloating. This maximum temperature could not be determined in the case of all the siliceous fire clays described because the safe limit to which our laboratory kilns can be fired is below the vitrification temperature of the samples.

TABLE 16.—*Data on ceramic tests of Kansas siliceous fire clays*

Plastic and Dry Properties

Sample No.	Dry color	Water of plasticity percent	Shrinkage water, percent	Pore water, percent	Volume shrinkage, percent	Calculated linear shrinkage, percent	Time required to slake 1" cube, percent	Modulus/ Rupture lbs. per sq. in.
C-29-3	light gray	17.8	8.1	9.9	16.8	5.3	136	477
C-43-4	gray	19.8	8.7	11.1	18.1	5.7	44	302
El-2-04	gray	15.8	5.8	10.0	13.1	4.2	55	599
El-21-9	gray	1.73	7.1	10.2	14.9	4.7	114	296
El-60-6	gray	16.2	5.9	10.4	11.4	3.7	13	63
El-60-13	gray	16.2	4.6	11.6	9.2	3.0	18	92
El-60-C	dark gray	18.6	6.3	12.3	12.2	3.9		242
El-78-3	dark gray	18.3	6.6	11.7	12.4	4.0	54	166
El-85-3	dark gray	20.0	7.1	12.9	13.8	4.4	15	233
El-85-4	gray	16.5	7.3	9.3	14.9	4.7	13	188
F-3-2	nearly white	23.4	9.6	13.8	18.6	5.9	4	225
L-6-6	cream gray	26.0	13.8	12.2	27.1	8.3	18	488
L-6-13	gray	22.6	13.3	9.3	26.6	8.2	56	337
L-10-01	gray	24.1	12.8	11.3	25.9	8.0	84	369
O-4-16	gray	19.2	7.5	11.7	15.4	4.9	18	367
O-4-C	gray	20.9	10.5	10.4	21.9	6.8		426
TC-2-10	gray	24.2	11.6	12.6	22.8	7.1	22	285
W-1-4	light gray	17.5	6.5	11.0	13.1	4.2	22	218
W-1-B	gray	21.8	9.6	12.2	19.5	6.1		472

TABLE 16.—*Data on ceramic tests of Kansas siliceous fire clays*

Fired Properties

Sample No.	Fired to cone	Fired color	Volume shrinkage, percent	Calculated linear shrinkage, percent	Absorption, percent	Apparent porosity, percent	Apparent specific gravity	Bulk specific gravity	Hardness†	Best firing range (pyrometric cone)	Pyrometric cone equivalent
C-29-3	04	ivory	2.3	0.8	10.4	20.8	2.53	2.00	S		
	02	ivory	3.3	1.1	9.6	19.4	2.52	2.03	S	02 to above 11	
	4	cream	10.0	3.5	5.3	11.7	2.49	2.20	H		
	8	cream	10.7	3.7	4.3	9.4	2.43	2.20	H		
	11	light buff	10.9	3.7	4.3	9.5	2.43	2.20	H		
C-43-4	03-04	cream	3.5	1.2	10.5	21.4	2.58	2.03	S	03 to above 5	
	5	cream	7.6	2.6	7.7	16.2	2.53	2.11	H		28-29
El-2-04	05	cream	1.7	0.6	11.2	22.5	2.58	2.00	S		
	02	cream	2.9	1.0	10.8	21.5	2.55	2.00	S	1 to above 12	
	5	cream	6.3	2.2	7.8	16.4	2.50	2.09	S		
	8	cream	10.0	3.5	5.2	11.4	2.48	2.20	S		
	11-12	light buff	10.8	3.7	3.6	8.0	2.39	2.20	H		
El-21-9	05	cream	*0.8+	*0.3+	11.4	22.4	2.59	1.97	H		
	02	cream	3.5	1.2	10.4	20.8	2.53	2.00	H	1 to above 11	
	5	cream	11.7	4.1	4.4	9.6	2.43	2.20	H		
	8	cream	14.2	5.0	3.1	7.1	2.48	2.30	H		
	11	ivory	12.0	4.2	2.5	5.6	2.36	2.23	H		
El-60-6	03	white	2.0	0.7	14.8	27.8	2.60	1.88	S		
	01	white	2.9	1.0	14.9	28.3	2.65	1.90	S	above 18	
	5	white	4.3	1.5	14.9	28.1	2.63	1.89	S		30
	9	white	4.7	1.6	14.2	27.0	2.60	1.90	S		
	12	ivory	5.2	1.8	13.7	26.2	2.59	1.91	S		

	14-15	ivory	3.1	1.1	13.4	25.4	2.55	1.90	S	
	18	buff		2.2	14.0				S	
EI-60-13	05	white	1.7	0.6	14.4	27.4	2.62	1.90	S	
	01	white	2.4	0.8	15.3	29.4	2.72	1.92	S	above
	5	white	3.1	1.0	14.8	28.2	2.65	1.90	S	18
	9	white	4.7	1.6	14.0	26.6	2.60	1.91	S	
	12	ivory	4.5	1.5	13.3	25.6	2.58	1.92	S	
	14-15	ivory	2.1	0.7	14.2	26.6	2.56	1.88	S	
	16	ivory	1.4	0.5	13.5	25.2	2.50	1.87	S	
	18	ivory		0.9	14.4				S	
El-60-C	05	buff	1.0	0.3	18.3	32.9	2.68	1.80	S	13 to
	1	buff	5.2	1.7	15.2	27.4	2.48	1.80	S	16
	4	buff	7.2	2.5	14.6	27.8	2.63	1.90	S	
	9	cream	7.2	2.5	13.9	26.4	2.58	1.90	S	
	12	cream	8.4	2.9	13.3	25.2	2.54	1.90	S	
	14-15	buff	8.8	3.0	10.4	20.2	2.43	1.94	H	
	16	dark tan	9.8	3.4	4.8	9.8	2.25	2.03	H	
El-78-3	01	cream	1.4	0.5	19.1	32.4	2.52	1.70	S	
	5	cream	4.9	1.7	15.8	28.4	2.51	1.80	S	above
	9	cream	5.4	1.8	14.5	26.1	2.44	1.80	S	
	11	cream	4.0	1.4	16.3	28.8	2.49	1.77	H	14-15
	14-15	buff	4.4	1.5	15.0	26.3	2.39	1.78	H	
El-85-3	03-04	ivory	2.9	1.0	16.2	29.2	2.54	1.80	S	15 to
	01	ivory	3.9	1.3	15.9	29.1	2.58	1.83	S	above
	5	cream	6.3	2.2	14.2	27.0	2.60	1.90	S	
	9	cream	6.8	2.3	13.9	26.4	2.58	1.90	S	16
	11	cream	7.2	2.5	13.2	25.1	2.54	1.90	H	
	14-15	buff	6.0	2.0	12.7	24.1	2.50	1.90	H	
	16	buff	13.4	4.7	8.9	17.9	2.45	2.01	H	

TABLE 16.—*Data on ceramic tests of Kansas siliceous fire clays, continued.*

Sample No.	Fired to cone	Fired color	Volume shrinkage, percent	Calculated linear shrinkage, percent	Absorption, percent	Apparent porosity, percent	Apparent specific gravity	Bulk specific gravity	Hardness†	Best firing range (pyrometric cone)	Pyrometric cone equivalent
El-85-4	05	ivory	1.0	0.3	13.4	25.9	2.61	1.93	S		
	01	ivory	2.7	0.9	12.2	24.3	2.64	2.00	S	5 to 15	
	5	cream	5.2	1.8	10.1	20.2	2.52	2.01	S		
	8	cream	5.1	1.7	9.6	19.2	2.48	2.00	S		
	11-12	cream	5.3	1.8	9.0	17.9	2.44	2.00	H		
	14-15	gray buff	11.6	4.0	5.7	11.8	2.34	2.06	H		
F-3-2	04	cream	5.3	1.8	12.2	23.6	2.53	1.93	S	02 to 12	
	6-7	cream	15.2	5.4	5.7	12.3	2.45	2.15	H		
L-6-6	07	cream	4.2	1.4	13.5	25.7	2.56	1.90	S		
	01	cream	6.7	2.3	11.9	23.7	2.61	1.99	S	1 to above 11	
	5	cream	10.9	3.8	9.0	18.5	2.51	2.05	S		
	8	cream	14.9	5.2	6.6	13.9	2.46	2.12	H		
	11	cream	14.8	5.2	4.1	8.7	2.31	2.11	H		
L-6-13	06	cream	4.4	1.5	12.9	24.7	2.54	1.91	S		
	01	cream	5.3	1.8	12.2	23.3	2.49	1.91	S	4 to above 12	
	4	cream	8.1	2.8	10.0	19.9	2.50	2.00	H		
	8	cream	8.9	3.1	7.5	14.9	2.35	2.00	H		
	12	cream	10.1	3.5	7.7	15.4	2.37	2.00	H		
L-10-01	06	cream	1.0	0.3	13.9	26.3	2.58	1.90	S		
	01	cream	1.9	0.6	12.7	24.2	2.50	1.90	S		
	5	cream	3.7	1.3	11.6	23.3	2.61	2.00	S	12 to 15	
	8	cream	3.8	1.3	11.1	22.2	2.57	2.00	S		26
	12	cream	4.1	1.4	10.9	21.7	2.56	2.00	S		

	14-15	buff	3.2	1.2	9.8	19.1	2.41	1.95	S		
	16	dark tan	1.3	0.4	3.6	6.8	2.06	1.92	H		
O-4-16	05	ivory	1.8	0.6	11.3	22.5	2.58	2.00	S		
	01	ivory	3.8	1.3	9.9	19.7	2.49	2.00	S	02 to	
	4	cream	9.2	3.2	6.5	13.8	2.47	2.13	S	above	
	8	cream	9.8	3.4	5.4	11.8	2.50	2.20	H	12	
	12	cream	10.7	3.7	4.0	8.8	2.41	2.20	H		
O-4-C	04	cream	2.3	0.8	10.8	21.5	2.55	2.00	S		
	2	cream	5.3	1.8	8.5	17.5	2.54	2.10	S	04 to	
	4	cream	6.4	2.2	7.5	15.8	2.49	2.10	S	above	
	9	cream	7.4	2.5	5.5	11.6	2.37	2.10	H	12	
	12	buff	8.6	3.0	4.5	9.7	2.39	2.16	H		
TC-2-10	06	cream	0.7	0.2	12.1	23.4	2.52	1.93	S		
	02	cream	3.3	1.1	12.6	24.1	2.52	1.91	S	5 to	27-28
	5	cream	5.4	1.8	10.7	21.4	2.54	2.00	S		
	9	cream	3.9	1.3	10.3	20.4	2.50	1.99	S	14	
	12	cream	3.8	1.3	9.9	19.4	2.43	1.96	S		
	14-15	buff	6.4	2.2	6.7	13.4	2.30	1.99	H		
W-1-4	02	buff	4.8	1.6	10.4	20.8	2.54	2.01	S		
	4	cream	4.0	1.4	10.4	20.8	2.53	2.00	S	02 to	
	9	cream	2.8	0.9	9.9	19.7	2.49	2.00	S	above	26
	12	cream	2.0	0.7	9.9	19.5	2.47	1.99	H		
	14-15	buff	5.7	1.9	6.8	13.2	2.23	1.93	H	14	
W-1-B	2	cream	4.0	1.4	12.0	23.9	2.63	2.00	S		
	4	cream	5.5	1.9	9.8	19.6	2.49	2.00	S	3 to	
	8	cream	5.4	1.8	9.3	18.6	2.46	2.00	S	above	
	12	light buff	5.9	2.0	7.1	14.2	2.34	2.01	S	14	
	14-15	tan	5.2	1.8	5.7	11.5	2.29	2.03	H		

*Plus sign (+) indicates expansion.

†(S) indicates softer than steel; (H) indicates harder than steel.

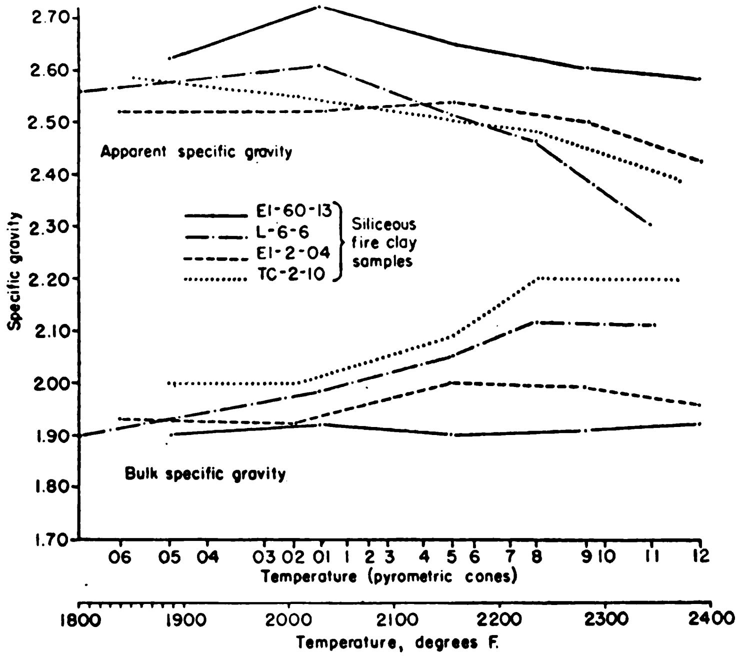

FIG. 7.—Graph showing changes in apparent specific gravity and bulk specific gravity over the range of firing temperatures for typical siliceous fire-clay samples.

The most unusual feature of the siliceous fire clays tested is that only slight changes occur in the test bricks over a wide range of temperatures (Fig. 7). The most extreme example is El-60-13, the linear shrinkage of which increased but 0.9 percent over a firing range of 17 cones (504° F.) and the absorption decreased but 1.1 percent within the same range cone 05 to cone 12. From cone 14-15 to cone 18 shrinkage values decreased on sample El-60-13, but absorptions remained about the same. This clay is underfired at cone 18. The greatest change occurred on firing sample F-3-2. Over a firing range of 11 cones (288° F.) the linear shrinkage increased 3.6 percent and the absorption decreased 6.5 percent.

The siliceous fire clays are particularly suitable for use in the manufacture of firebricks and other refractories. For this purpose it is probable that many of the clays would be fired sufficiently high at temperatures ranging from cone 10 to cone 14. However, in most cases higher temperatures would be desirable so that a greater proportion of the silica could be taken into solution in the glassy phase, thus eliminating some volume changes on heating and cooling due to the presence of free quartz.

Highly Siliceous Fire Clay

Any fire clay having a silica content exceeding 80 percent is classed in this report as a highly siliceous fire clay (Table 4). This class actually includes clayey silts having sufficient plasticity and bonding power to permit forming into test bricks.

The thickest beds of light-firing clay found in the Dakota formation in Kansas are highly siliceous fire clays. One such bed having a thickness of 40 feet (L-9-7) is described in succeeding pages.

Location and Occurrence of Samples Described

Seven samples from six localities are described in the following section on highly siliceous fire clays. The counties in which the samples were obtained with the location index numbers follow: Ellsworth County, El-20, El-73, and TC-2; Lincoln County, L-9; Ottawa County, O-20; and Washington County, W-57 (Pl. 1).

(El-20) Twenty-two pits distributed in six groups, and covering about a half section, were excavated in the area given the location index number El-20. In fact, the pits were distributed over too large an area to be given correctly one location number. Therefore, to avoid confusion, the numbers given to beds in the three west groups are prefixed with a W, and those given to the beds in the three east groups are prefixed with an E.

The pits at location El-20 also form a nearly continuous series with those at El-21, described under siliceous fire clay. Although a total of 40 pits was excavated at both locations, they were distributed in groups of 2 to 5 pits in vertical series, so that the maximum thickness of beds exposed in any one series was 50 feet. Furthermore, some of the beds can be identified in each series of pits throughout the El-20 and El-21 area. In the El-20 groups of pits the bed of white kaolinitic silt, designated bed E5 and W5 in the measured sections given below, is the one most easily identified and correlated.

Bed W5, with which we are particularly concerned here, is an unusual material. It is a very fine-grained clayey silt which easily could be mistaken for kaolin. Almost all of this material will pass a 200-mesh Tyler screen.

Measured section of pits from which sample El-20-W5 was taken, SE¼ sec. 29, T. 15 S., R. 7 W., Ellsworth County.

Bed No.		Thickness, feet
	Dakota formation	
	Terra Cotta clay member	
	Soil and residual contains blocks of sandstone	1.9
W7.	Clay, fairly plastic, very light gray mottled with red and yellow	5.2
W6.	Clay, fairly plastic, smooth, nearly white with some lavender stain	2.7
W5.	**Silt, kaolinitic, very fine-grained, smooth, nearly white with a very small amount of yellow stain**	**6.8**
W4.	Clay, fairly plastic, gray to light gray with red and yellow mottling in upper 2.5 feet	3.8
W3.	Clay, plastic, gray with some yellow stain; some fine sand on bedding planes; contains selenite in small amounts	4.3
W2b.	Clay, fairly plastic, gray with some brown, yellow, and red mottling	4.8
W2a.	Clay, plastic, gray with slight yellow stain; contains an ellipsoidal mass of clayey sandstone or siltstone 1 foot in diameter and 4 inches thick	3.0
	Total thickness of bed W2 .... 7.8	
W1.	Clay, silty to plastic, gray with red and yellow mottling	2.7
	Total thickness of measured section	35.2

Bed EA in the measured section given below is a composite or combination bed made up of clay sampled from beds E4, E5, E6, E7, and E8 combined in proportion to the thickness of the beds. The same result would have been attained by taking as one sample the entire thickness of 12 feet from the top of bed E3 to the top of bed E8.

Measured section of pits from which sample El-20-EA was taken, SW¼ sec. 28, T. 15 S., R. 7 W., Ellsworth County.

Bed No.		Thickness, feet
	Dakota formation	
	Terra Cotta clay member	
	Residual containing sandstone fragments	0.7
E10.	Clay, silty, yellow and gray	3.9
E9.	Sandstone to silt, clayey, yellow and gray; contains pellets of limonite and hematite	3.0
Top of bed EA		
E8.	**Clay, plastic, light gray at top and dark gray lignitic at bottom**	**2.9**
E7.	**Kaolin, white, banded with light gray**	**0.5**

E6.	**Clay, slightly silty, lignitic, dark gray with slight yellow stain**	**2.9**
E5.	**Silt, kaolinitic, fine-grained, soft, nearly white, with some yellow stain near middle**	**5.0**
E4.	**Clay, very silty, lignitic, gray**	**1.8**
Bottom of bed EA; total thickness, 12.0 feet		
E3.	Clay, plastic, light gray with fine mottling of red	2.7
E2.	Silt, clay and sand in thin beds of gray, buff, and yellow	7.9
E1.	Clay, plastic, gray with some brown, red, and yellow mottling	5.9
	Total thickness of measured section	35.2

The bottom of this measured section is approximately 35 feet above the top of the Kiowa shale formation. High quality fire-clay beds were found in many places in this interval. In fact, such beds were sampled at location El-33, 0.5 mile south and at location El-102, 1 mile east of El-33.

(El-73) Clay beds nearly identical to those sampled at location El-73 were also sampled at location El-78, which is less than 1 mile southeast of El-73. Location El-78 is described under siliceous fire clay. Clay beds occurring at the same stratigraphic position in the Janssen clay member were sampled in this area at locations El-74, El-85, El-86, and El-91.

Measured section of pits from which sample El-73-A was taken, SW¼ SE¼ sec. 19. T. 14 S., R. 7 W., Ellsworth County.

Bed No.			Thickness, feet
	Dakota formation		
	Janssen clay member		
	Soil and residual		1.0
8.	Hematite, sandy		0.5
7.	Sandstone, fine-grained, to siltstone in thin even beds, light gray to light yellow; contains thin streaks of gray clay and limonite		4.3
6.	Siltstone and some very fine sandstone, thin-bedded, light gray to light yellow; concretionary limonite interbedded		10.2
Top of Bed A			
5b.	**Clay, very silty, massive, dark gray with some light yellow on joints containing selenite**		**5.3**
5a.	**Clay, silty, thin-bedded, very dark gray wth some yellow brown on joints**		**2.6**
	Total thickness of bed 5	**7.9**	
4.	**Clay, very silty, dark gray, thin-bedded**		**6.0**
3b.	**Clay, very silty, dark gray grading downward to silt**		**2.2**

3a. Silt to fine-grained sandstone, nearly white, and lignite, in thin alternating beds		**7.2-9.7**
Total thickness of bed 3	**9.4-10.7**	
2c. Clay, silty, light gray with light yellow on joints; contains some selenite		**2.0—**
2b. Clay, slightly silty, hard but smooth, very dark gray with some brown on joints; contains some selenite		**4.5**
2a. Clay, silty, light gray; contains lignitized sticks		**2.4**
Total thickness of bed 2	**7.6-8.9**	
Bottom of Bed A; total thickness of bed A, 32.2		
1. Silt, light gray with thin seams of lignite; contains some pyrite		1.9
Total thickness of measured section		50.1

There is considerable local difference in thickness of beds at this location. For example, bed 3 is almost entirely missing on an exposure about 100 yards northeast of the measured section described, whereas division (c) of bed 2 is 9.0 feet thick on the same exposure. A sample taken of division (c) at this place proved in the tests to be an excellent siliceous fire clay, firing white at low temperatures and ivory at high temperatures.

The maximum thickness of overburden above bed A is about 20 feet, and in some places it is only a few inches.

Bed 8 of this location is probably the uppermost bed of the Dakota formation, although no exposures of Graneros shale were found in the immediate vicinity.

(L-9) Lincoln County location L-9 is about 5 miles northeast of El-73 previously described, and less than 0.5 mile north of the Lincoln-Ellsworth County line. Location L-13 is 1 mile northeast of L-9; L-10, described under siliceous fire clay, is 5 miles north. Bed 7 of location L-9 is the thickest bed of light-firing clay sampled in the Dakota formation.

Measured section of pits from which sample L-9-7 was taken, SE¼ sec. 33, T. 13 S., R. 7 W., Lincoln County.

Bed No.	Thickness, feet
Dakota formation	
Janssen clay member	
Clay, silt, and sand residual	0.0-4.0
7. Clay, silty, gray; contains a few thin lenses of yellow, fine-grained sandstone and silt 1 to 5 inches thick and scattered fragments of lignite	**40.0**

6.	Sandstone, yellow, and clay, gray, interbedded	5.3
5.	Clay, fairly plastic, light gray, with some yellow stain	7.3
4.	Clay, plastic, gray with some yellow stain at top and a slight amount of red at bottom	8.5
3.	Clay, mostly plastic, gray to light gray with a small amount of red mottling	17.0
2.	Clay, silty, gray with irregular limonitic yellow bands	6.9
Terra Cotta clay member		
1.	Clay, mostly plastic, gray and red mottled	9.5
	Sandstone, fine-grained, quartzitic	0.5
	Total thickness of section measured	95.0

Beds 2 to 7, inclusive, were combined for testing into one bed having a total thickness of 85.0 feet. Bricks made from this combination fired to a dark buff.

There is considerable local variation in the thickness and character of the beds in the immediate area. The maximum thickness of bed 7 is 40 feet. About 0.5 mile west it thins to 20 or 30 feet, and where the clay is much purer it fires to colors ranging from white to light buff.

Lignite occurring near the top of the Janssen clay member has been mined here, and is described by Whitla (1940).

(O-20) Location O-20 is the index number for an Ottawa County location 8 miles west of Bennington, and 0.25 to 0.625 mile north of Kansas highway no. 18. Pits were excavated at two other locations in the immediate area. Location O-25 is 0.75 mile east of O-20, and O-21 is 1 mile north of O-25.

Measured section of pits from which sample O-20-1 was taken, W½ sec. 4, T. 12 S., R. 1 W., Ottawa County.

Bed No.			Thickness, feet
Dakota formation			
	Terra Cotta clay member		
	Soil and residual		1.4
6b.	Clay, slightly silty, gray; contains a few small selenite crystals		2.3
6a.	Clay, silty, gray with some light yellow stain		4.0
	Total thickness of bed 6	6.3	
5.	Clay, silty, very light gray with small amount of yellow stain, contains some lignite		5.1
4b.	Clay, silty, lignitic, ash gray with some limonitic yellow		1.0
4a.	Clay, very silty, very light gray with some yellow bands		1.0
	Total thickness of bed 4	2.0	

3.	Clay, silty, very light gray with no stain; contains some selenite	4.8
2.	Clay, very silty, gray with yellowish tinge; contains chunks of lignitized wood and small pyrite nodules	1.4
1.	**Clay, silty, gray to light gray with no stain; contains small chunks of lignitized wood in which some pyrite has been deposited**	8.5
	Total thickness of section measured	29.5

The clay beds occurring above bed 1 should not be considered as useless overburden. All of the beds above bed 1 fired to a buff or cream color with the exception of the thin bed 2 which fires to a pink. All the clay beds described in the measured section (1 to 7, inclusive) were combined in proportion to the thickness of the beds, and tested as one bed having a total thickness of 28 feet (bed A). This composite bed fired to colors ranging from cream to buff, and its other ceramic properties are very similar to bed 1.

The minimum thickness of overburden above bed 6, 1.4 feet, is shown in the measured section. The thickness of overburden does not exceed 8 feet, however, over an area of several acres.

(TC-2) Location TC-2 is described under the heading siliceous fire clay, where complete data are given on bed 10 (Sample no. TC-2-10).

Bed 1, a highly siliceous fire clay at this location, was also sampled at location El-12, less than 1 mile north of TC-2. Location El-2 also is described under the heading siliceous fire clay, where the results of tests are given for bed 04 (samples no. El-2-04), which is the one correlated with bed 1 at location TC-2 (sample TC-2-1).

Measured section of pits from which sample TC-2-1 was taken, W½ SE¼ sec. 15, T. 15 S., R. 6 W., Ellsworth County.

Bed No.		Thickness, feet
	Dakota formation	
	Terra Cotta clay member	
15-4.	(Described in division of siliceous fire clay, location TC-2)	95.3-95.8
3.	Clay, plastic, with some yellow stain	4.2
2.	Clay, silty, lignitic, dark pinkish gray; contains plant fossils and some limonite	1.0-1.5
1.	**Clay, silty to very silty, light gray with some yellow stain, limonitic joint filling**	7.0
	Total thickness of section measured	108.0

Bed 2, overlying bed 1, is probably lenticular, or at least not continuous. Bed 3 is a plastic fire clay firing to a light-buff color. A combination of beds 1 and 3, eliminating bed 2, would produce a more generally usuable clay than bed 1 used alone.

The thickness of bed 1 is several feet greater than shown in the measured section. Several tons of this clay were removed for a commercial scale test, and the clay taken out below the bottom of the measured section was reported to be of greater purity than the upper 7.0 feet which is shown. The equivalent of bed 1, occurring at the same stratigraphic position at location E1-2 (sample E1-2-04) is 18 feet thick.

(W-57) The clays sampled at location W-57 were taken from four pits excavated 4 miles north of Clifton and 0.5 mile east of the gravelled county highway between Clifton and Haddam. Location W-57 and one other 3 miles north of Clifton (W-58) were the only locations at which clays were sampled over an area covering three townships in the southwest corner of Washington County. Further work should be done in this area and in an adjoining area to the south in Clay County. Our program of clay investigations was curtailed in these areas because of a lack of WPA labor.

Measured section of pits from which sample W-57-2 was taken, NE¼ NW¼ sec. 13, T. 15 S., R. 1 E., Washington County.

Bed No.			Thickness, feet
	Dakota formation		
	Terra Cotta clay member		
	Soil and residual containing fragments of sandstone		0.5
5.	Clay, fairly plastic, yellow and gray		1.5
4c.	Clay, slightly silty, lignitic, dark gray with some yellow stain		2.5
4b.	Silt, yellow and gray		2.2
4a.	Clay, fairly plastic, gray with 2 yellow streaks 0.3 foot wide containing some concretionary limonite		4.2
	Total thickness of bed 4	8.9	
3d.	Clay, fairly plastic, gray with slight yellow stain		2.6
3c.	Clay, slightly silty, gray; contains lignite fragments and some selenite		2.5
3b.	Clay, plastic, light gray with some yellow on slickenside joints; contains a small amount of gypsum		1.7
3a.	Clay, fairly plastic, gray with some yellow stain on joints; contains fragments of lignite and some gypsum		3.3
	Total thickness of bed 3	10.1	

2. Clay, silty to very silty, gray with some yellow in upper 1.9 feet; contains particles of lignite and some small needle-like crystals of selenite	**4.7**
1. Clay, very silty, gray with paper thin streaks of wnite sand; contains some concretionary limonite	2.0
Total thickness of section measured	27.7

Bed 2 is not the most important clay bed at this location, but is discussed because it is representative of the highly siliceous fire clays. Bed 3 is a cream- to light buff-firing refractory clay, and bed 4 fires to a buff. Beds 2, 3, and 4 were combined into one bed having a total thickness of 23.7 feet. In the laboratory tests this combination bed (W-57-A) fired to a buff color.

The clay beds in the local area are laterally fairly uniform in thickness, but vary considerably in color, particularly in the amount of yellow coloration in the gray clays. This may be due to differences in the degree of oxidation of iron compounds on exposure to weathering conditions. If this is true the fired color of the clay beds would be much more uniform laterally than they are in the unfired state.

If the entire thickness of light-firing clay available at this location were used, the cost of mining would be at a minimum because the overburden is thin and could be disposed of by hauling down hill to barren ground; also the clay could be loaded down-hill into trucks or other means of conveyance.

The visible reserves, although large in respect to the general area, are relatively small in the immediate vicinity of the outcrop sampled.

Mineralogic Properties

The discussion of the mineralogic properties of the other classes of Kansas fire clay applies equally well to the highly siliceous clay, with the exception that the proportion of quartz to clay minerals is obviously higher in the latter. As arbitrarily defined in this report, any refractory clay having a silica content exceeding 80 percent is a highly siliceous fire clay. Calculating from the chemical analyses, a clay containing 80.1 percent silica and 14 percent alumina would be composed of approximately 63.5 percent quartz and 35.5 percent kaolinite. This percentage of kaolinite would hold in chemical combination 14 percent alumina, 16.5 percent silica, and 5 percent water of the total constituents of the clay sample.

The most highly siliceous sample tested, in fact a kaolinitic silt, contains approximately 92 percent silica, of which 85.5 percent is uncombined quartz and 6.5 percent is a constituent of the kaolinite molecule. Kaolinite comprises less than 14 percent of the sample. The approximate mineralogic composition of the highly siliceous fire clays therefore ranges from 63.5 percent quartz and 35.5 percent kaolinite to 83.0 percent quartz and 14.0 percent kaolinite.

The particle size of the quartz present in the highly siliceous fire clay is very small. In the case of sample E1-20-W5 less than 1 percent remains on a 200-mesh Tyler screen (opening 0.074 mm). A considerable proportion of the quartz probably would be included in the clay fraction in a classification based on particle size, which would include in the clay fraction all particles 0.005 mm or less in diameter.

Chemical Properties

Highly siliceous fire clay (Table 17) differs chemically from the less siliceous types only in that it contains a higher percentage

TABLE 17.—*Chemical composition of Kansas highly siliceous fire clays described in this report* (Analyses by Raymond Thompson and Russell Runnels)

	Constituents, percent								
Lab. No.	Silica (SiO_2)	Alumina (Al_2O_3)	Iron oxide (Fe_2O_3)	Titanium oxide (TiO_2)	Calcium oxide (CaO)	Magnesium oxide (MgO)	Potassium and sodium oxides (K_2O Na_2O)	Ignition loss	Total determined
E1-20-EA	80.62	13.20*	0.71	....	0.58	0.47	....	3.98	99.56
E1-20-W5	91.36	3.71	0.54	1.06	0.25	0.35	1.30	1.40	99.97
†E1-73-A	76.40	10.35	1.40	0.91	0.88	0.55	....	7.76	98.25
L-9-7	80.50	10.79	1.72	0.86	0.29	0.68	1.00	4.18	100.02
O-20-1	82.30	9.15	1.23	0.65	0.75	0.09	2.06	4.22	100.45
TC-2-1	82.83	9.89	1.14	1.20	0.04	trace	1.77	3.07	99.94
W-57-2	80.03	12.44	0.73	0.36	0.34	0.38	2.02	3.79	100.09
‡W-57-A	68.17	17.10	2.14	2.35	0.35	0.64	3.71	5.65	100.11

*Includes titanium

†Highly siliceous because of alumina-silica ratio

‡A plastic fire clay, included in this table for reasons explained in the text

of silica, which is arbitrarily fixed by definition as exceeding 80 percent (Table 4). Inasmuch as the impurities such as iron oxide, calcium and magnesium oxides, and the alkalies seem to be associated with the clay minerals, the finely divided quartz acts as a diluent and thus lowers the percentage of impurities present in the more siliceous clays. The impurities are active fluxes, and this probably accounts for the fact that the P. C. E. of the siliceous clays does not vary significantly from that of the more highly aluminous clays.

Ceramic And Other Physical Properties

Despite the fact that nonplastic materials dominate in the highly siliceous fire clays, they are all sufficiently plastic to permit hand molding, and the majority of the samples tested were easily workable and ware can be formed from them by the method of stiff-mud extrusion. In the laboratory tests we encountered no problems in drying or firing, due largely to open texture of the clay. No cracking occurred while cooling the fired bricks in the kiln, although the cooling was in some cases accomplished in as short a time as 24 hours. Re-heating in contact with gas flame to a bright red heat, and cooling to room temperature can be accomplished in a period of 2 to 3 hours without cracking.

The firing tests are incomplete because many of the highly siliceous fire clays are far short of vitrification at the maximum temperature attainable in our large gas-fired test kiln. Data on these tests are given in Table 18.

Absorption, porosity, and specific gravity data on most of the highly siliceous fire clay samples tested indicate that a product made from this type of clay should be fired to cone 12 or higher if it must withstand exposure to the weather (Fig. 8). If used in the manufacture of wall tile, firebrick, or other products which will not be subjected to saturation with water and freezing, the temperature to which the clay is fired will be determined by individual standards in regard to fired strength, resistance to abrasion, and resistance to crazing of glazes applied. Salt glazing tests at temperatures ranging from cone 8 to cone 14 have been uniformly successful. All other types of high temperature glazes have, however, resulted in shivering or dunting of the body. Low temperature glazes (cone 08-03) can be fitted to the highly siliceous body if it is previously fired to cone 8 or higher, although

TABLE 18.—*Data on ceramic tests of Kansas highly siliceous fire clays*

Plastic and Dry Properties

Sample No.	Dry color	Water of plasticity percent	Shrinkage water, percent	Pore water, percent	Volume shrinkage, percent	Calculated linear shrinkage, percent	Time required to slake 1" cube, minutes	Modulus/ Rupture lbs. per sq. in.
E1-20-W5	nearly white	20.2	1.2	19.0	1.9	0.6	13	
E1-20-EA	light gray	17.7	5.4	12.4	10.6	3.4		134
E1-73-A	gray	18.8	6.7	12.1	13.1	4.2		213
L-9-7	gray	16.0	6.7	9.3	13.6	4.3	40	223
O-20-1	gray	18.7	10.7	8.0	22.0	6.9	68	275
TC-2-1	very light gray	19.5	6.9	12.6	13.5	4.4	20	300
W-57-2	gray	16.4	5.6	10.8	11.1	3.6	120	438
W-57-A‡	gray	18.9	8.9	10.0	18.6	5.9		480

TABLE 18.—*Data on ceramic tests of Kansas fire clays, continued*

Fired Properties

Sample No.	Fired to cone	Fired color	Volume shrinkage, percent	Calculated linear shrinkage, percent	Absorption, percent	Apparent porosity, percent	Apparent specific gravity	Bulk specific gravity	Hardness†	Best firing range (pyrometric cone)
E1-20-W5	13-14	cream	*3.9+	*1.3+	25.2	37.7	2.41	1.50	S	14+
	18	pink buff		4.5+	29.3				S	
E1-20-EA	06	white	1.7+	0.6	15.3	29.0	2.66	1.89	S	
	01	ivory	0.5+	0.2	14.8	28.1	2.63	1.89	S	above 18
	5	cream	0.8	0.3	13.7	26.0	2.57	1.90	S	
	8	cream	1.5	0.5	12.9	24.5	2.51	1.90	S	
	11	cream	0.1	0.03	13.3	25.3	2.54	1.90	H	
	14-15	buff	3.0+	1.0+	12.9	23.4	2.38	1.82	H	
	16	dark buff	1.3+	0.4+	13.0	23.6	2.38	1.82	H	
	18	buff		0.9	13.7				H	
E1-73-A	04	light cream	0.9+	0.3+	17.5	31.6	2.63	1.80	S	
	2	light cream	0.1	0.03	16.8	30.2	2.61	1.80	S	above 12 to 16
	4	cream	1.7	0.6	16.3	29.4	2.55	1.80	S	
	9	cream	1.3	0.4	16.1	28.9	2.53	1.80	S	
	12	buff	0.4	0.1	15.5	27.9	2.50	1.80	S	
	16	brown	6.9	2.4	8.3	15.8	2.27	1.91	H	
L-9-7	03	cream	1.2+	0.4+	13.7	26.1	2.57	1.90	S	
	01	cream	1.5+	0.5+	13.6	25.9	2.56	1.90	S	
	5	cream	0.1	0.03	13.5	25.6	2.55	1.90	S	12 to 16
	8	cream	0.6	0.2	12.0	22.9	2.46	1.90	S	
	12	cream	0.4	0.1	12.6	24.0	2.50	1.90	S	

	14-15	buff	2.3	0.8	11.1	21.5	2.50	1.96	H	
	16	brown	3.6	1.2	3.9	7.58	2.13	1.98	H	
	18	brown		2.4	4.7				H	
O-20-1	01	buff	0.7+	0.2+	12.4	24.1	2.55	1.94	S	
	4	buff	0.4+	0.1+	11.4	22.1	2.49	1.94	S	
	8	buff	0.7+	0.2+	11.3	21.8	2.47	1.93	S	
TC-2-1	02	cream	1.0	0.3	13.9	26.6	2.62	1.92	S	
	5	cream	2.0	0.6	12.5	23.8	2.51	1.91	S	from 13 to 16
	9	cream	1.8	0.6	11.8	22.5	2.45	1.90	S	
	13	cream	0.8	0.3	11.7	22.2	2.44	1.90	S	
	14-15	buff	2.2+	0.7+	11.0	20.3	2.32	1.85	H	
	16	gray tan	0.7	0.2	5.2	10.0	2.13	1.98	H	
	18	brown		1.2	6.2				H	
W-57-2	04-05	buff	1.1	0.4	14.0	26.5	2.59	1.90	S	
	1	buff	2.0	0.6	11.9	22.7	2.47	1.91	S	
	4	cream	5.7	1.9	9.9	19.8	2.49	2.00	H	
	8	cream	6.8	2.3	9.5	18.9	2.47	2.00	H	
	12	cream	5.5	1.9	9.0	18.0	2.44	2.00	H	
‡W-57-A	04	light buff	8.9	3.1	7.3	15.8	2.56	2.16	S	
	02	cream	9.6	3.3	6.7	14.4	2.51	2.15	S	
	8	cream	12.3	4.3	4.0	8.9	2.43	2.21	H	
	12	light buff	13.5	4.7	2.7	6.1	2.35	2.21	H	

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*Plus sign (+) indicates expansion.

†(S) indicates softer than steel. (H) indicates harder than steel.

‡W-57-2 is a siliceous fire clay, included for reasons explained in text.

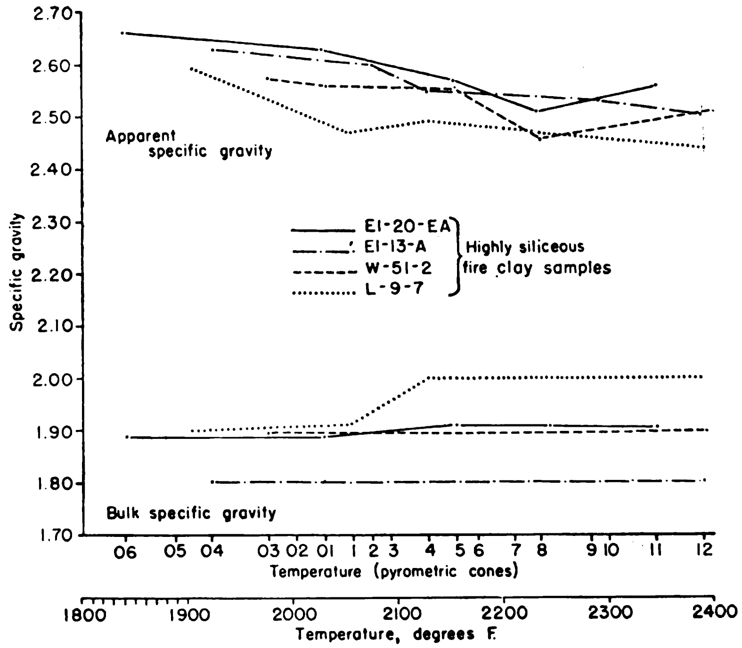

FIG. 8.—Graph showing changes in apparent specific gravity and bulk specific gravity over the range of firing temperatures for typical highly siliceous fire clay samples.

it is difficult to avoid crazing, which in some cases appears after several weeks or even months of storage.

It is probable that firebrick made from the more refractory Kansas highly siliceous fire clays can be used in installations subjected to temperatures a few degrees below the P. C. E. values of the clay (cone 26 to cone 30), and that they will be resistant to siliceous slags. It is not to be expected, however, that they will withstand abrupt changes of temperature or the attack of highly corrosive basic slags.

It is apparent from the few test firings up to cone 18 that the highly siliceous fire clays have a rather short vitrification range despite the high temperature to which they must be fired.

Résumé and Comparison of Ceramic Properties of Kansas Clays

As stated in the section describing siliceous fire clay, the chief difference between the four types of fire clay is the varia-

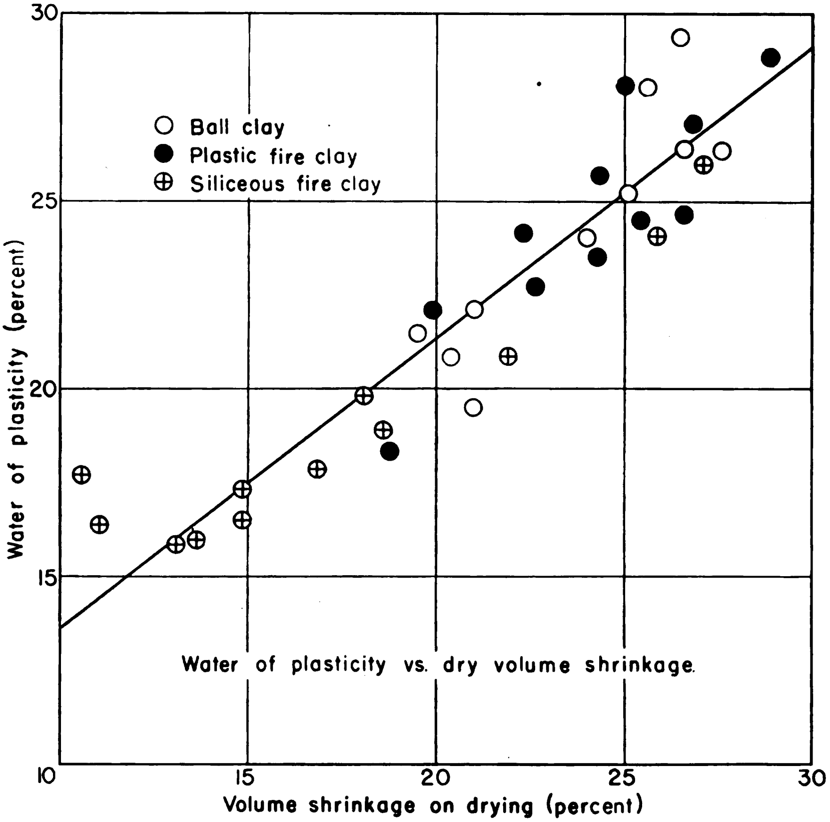

FIG. 9.—Chart showing correlation of water of plasticity and drying volume shrinkage for three types of clay.

tion in the proportion of free silica (quartz). By adding increasing amounts of potter's flint (minus 200-mesh quartz) to a pure ball clay we can produce a plastic fire clay, a siliceous fire clay, or a highly siliceous fire clay having ceramic properties characteristic of the naturally occurring clay. We should naturally expect, therefore, that ceramic properties due entirely to the clay mineral content will be increasingly obscured and modified by the physical and ceramic properties of quartz as the silica content becomes greater.

Because quartz does not absorb water, and because the large particle size of the quartz reduces the total surface area of the particles in the clay-quartz mixture, finely divided quartz (silt

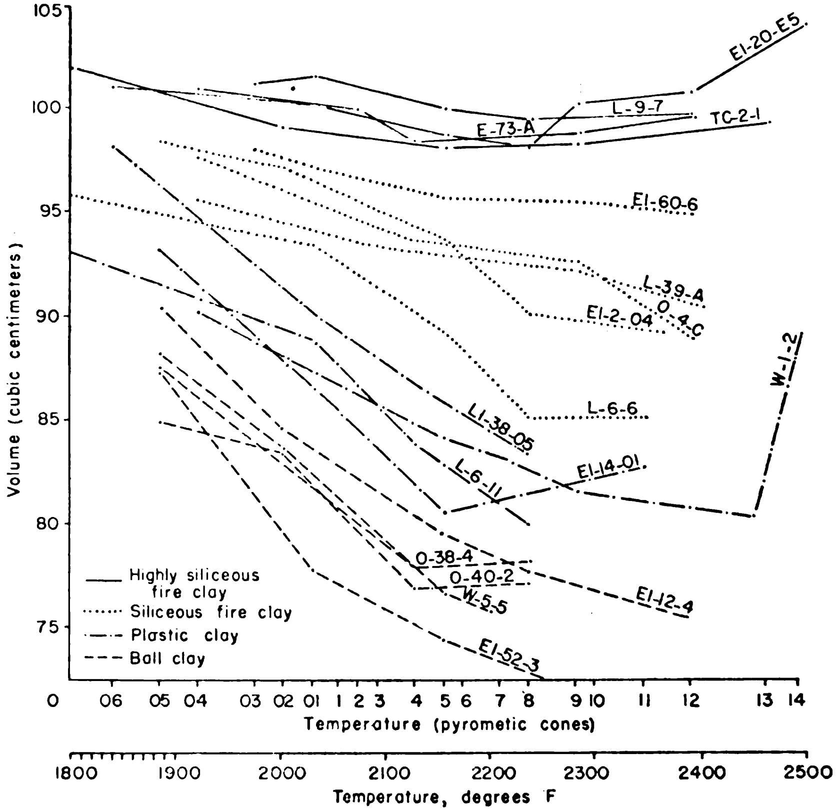

FIG. 10.—Curves showing change of fired volume with increasing temperatures for individual samples representing four types of clay (fired volumes based on dry volume of 100 cc).

in the natural state and potter's flint in artificial mixtures) has a decided effect on the plastic and drying properties of clay. As the silt content increases the water of plasticity decreases, together with the actual plasticity of the clay. The relative proportion of shrinkage water to pore water also decreases. Correlative with this is a decrease in volume shrinkage with increasing quartz (silt or flint). This relationship is clearly shown in Plate 2. The correlation of water of plasticity with volume shrinkage is also shown in Figure 9. For the manufacture of heavy clay products, or any type of product in which the cross-section is relatively great, and a low absorption on firing not required, clays containing

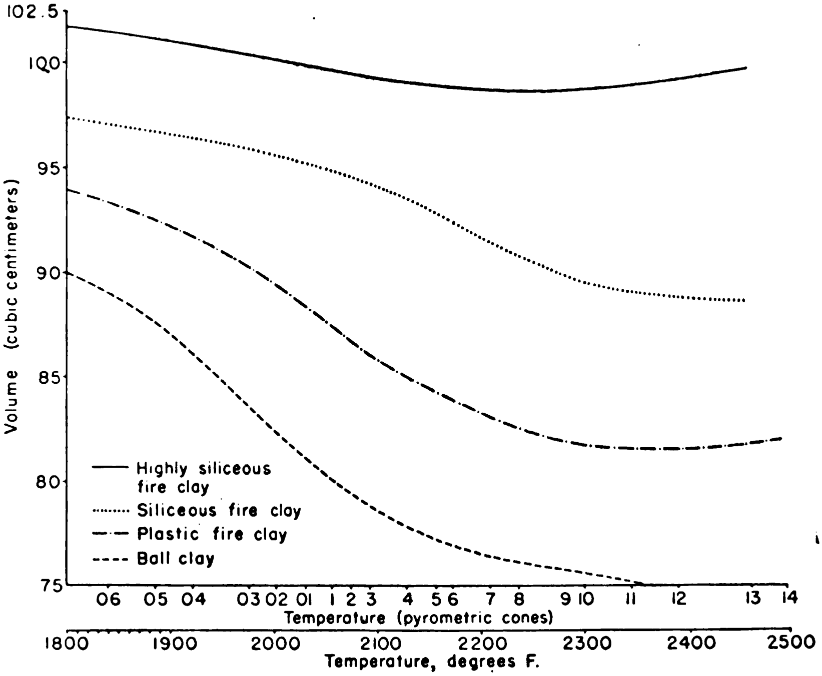

FIG. 11.—Average volume-temperature curves characteristic of four types of Dakota formation clay (fired volume based on dry volume of 100 cc). Note similarity to porosity-temperature curves.

a moderate amount of silt or fine sand, such as the plastic or siliceous fire clays, are much more easily handled than the extreme types such as the ball clay and highly siliceous fire clay. The intermediate types give more satisfactory results because, being of a relatively open texture, and containing less water in the plastic state, they can be formed with a minimum of lamination and dry with less shrinkage, distortion, or cracking. For some types of products, however, the ball clay or highly siliceous clay is required. The objectionable features are taken care of by use of different methods of forming and drying, and by the addition of other materials to the body, such as grog, feldspar, nepheline syenite, or volcanic ash. The nonplastic materials mentioned above reduce drying shrinkage and eliminate the objectionable features attending high shrinkage in ball clay and similar clays. The grog produces an open-firing body, but the other materials mentioned

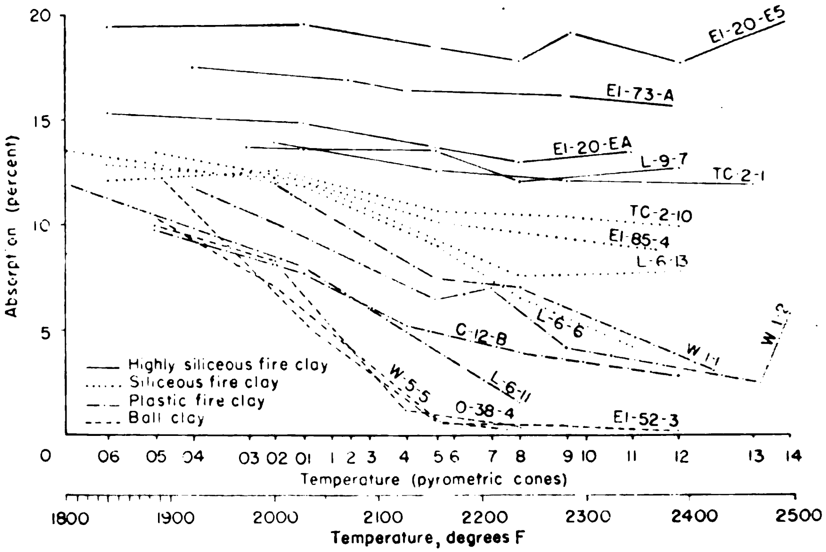

Fig. 12.—Graph showing range of absorption-temperature curves for individual samples representing four types of clay.

are used to produce a denser, or more nearly vitrified fired body. Such materials are not effective, however, below the temperatures at which a glassy phase results. Clay which is too highly siliceous for easy working is most easily modified by the addition of a more plastic clay. De-airing in the extrusion machine, in the case of structural clay and refractories, usually produces a denser and tougher body.

The characteristics which quartz (silt, sand, or flint) give to the fired properties (Harman and Parmalee, 1942) of a clay are somewhat similar to those produced in the plastic and dry clay. Quartz particles tend to produce an open-textured body, which allows for internal contraction and expansion, and at the same time allows for escape of water during the dehydration or water-smoking period of firing. Siliceous clays usually can be fired rapidly with little danger of cracking or black-coring. Inasmuch as quartz particles do not shrink on heating, the firing shrinkage is reduced in proportion to the quartz content. In fact quartz expands at certain temperatures, and in a highly siliceous body this property of quartz may cause the fired clay to be weakened, or even to crack or spall. Low-temperature or *alpha* quartz is

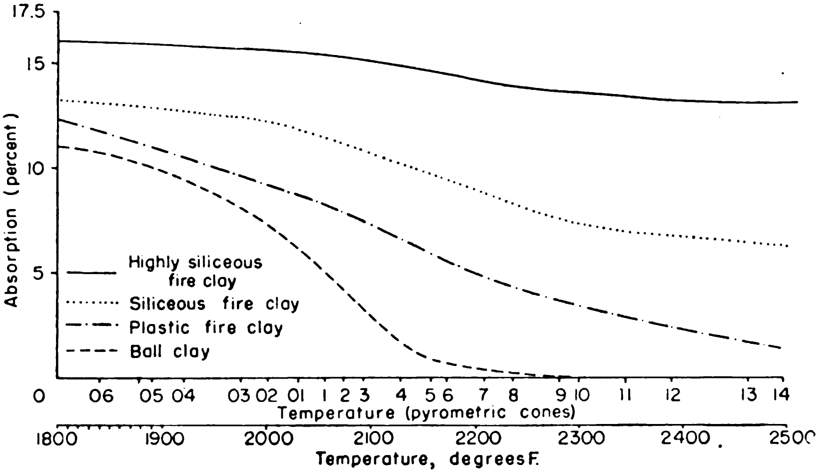

FIG. 13.—Average absorption-temperature curves characteristic of four types of clay.

changed to *beta* quartz at 1,063° F. This change is of little importance in firing clay. At 1,598° F. *beta* quartz begins to transform to tridymite, which has a density of 2.26 g./cc, as compared to a density of 2.65 g./cc for quartz. This is equivalent to a volume expansion of about 14 percent. Tridymite also has an *alpha* and a *beta* form with different densities. Fortunately the conversion of quartz to tridymite takes place slowly, and over a wide temperature range. Otherwise the expansion would invariably disrupt the clay body. At 2,678° F. tridymite begins to change to cristobalite, and fuses to amorphous silica at 3,142° F. Cristobalite, like quartz and tridymite, has an *alpha* and *beta* form, having volume difference of about 5 percent. On cooling a portion of the cristobalite converts to tridymite, and a small portion of the tridymite changes to quartz at even lower temperatures. Important volume changes occur on cooling, particularly with the rapid changes from *beta* to *alpha* cristobalite in the range 392° to 527° F., and the change from *beta* to *alpha* tridymite in the range 243° to 325° F. (McNamara, 1938). The volume changes occurring on either heating or cooling may cause disruption of the clay body if the temperature change is too rapid. We believe that the relative increase in volume of some of the highly siliceous fire clays above 2,250° F. is probably due to a delayed conversion of *beta* quartz to tridymite (Figs. 10 and 11).

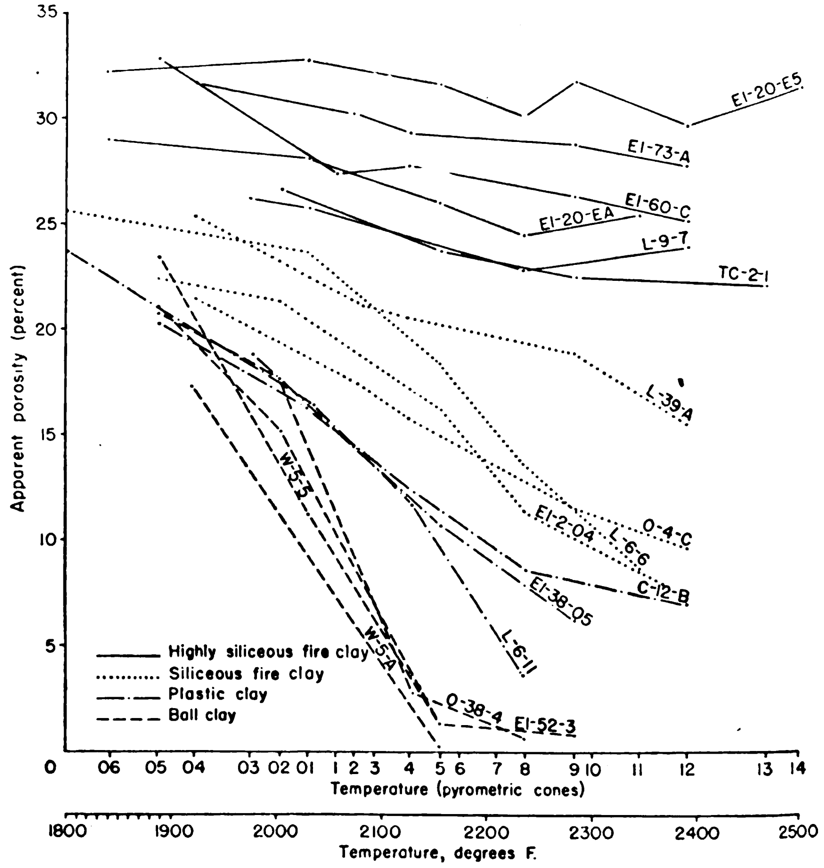

FIG. 14.—Graph showing range of porosity-temperature curves for individual samples representing four types of Dakota formation clay.

The general effect of finely divided quartz in a clay body is to lessen the changes produced in volume, absorption, and porosity with increasing temperature. If these changes in fired properties with increasing temperature are plotted graphically it will be seen that the curves for all the properties approximately have the same configuration (Figs. 10, 11, 12, 13, 14, and 16). Because the four types of clay discussed are not sharply defined, but grade from one to the other, the data on individual samples naturally reflect this gradation, although there is almost no overlapping of curves between types as shown on the graphs (Figs. 10, 12, and 14). We have plotted volume data as volume change in cubic

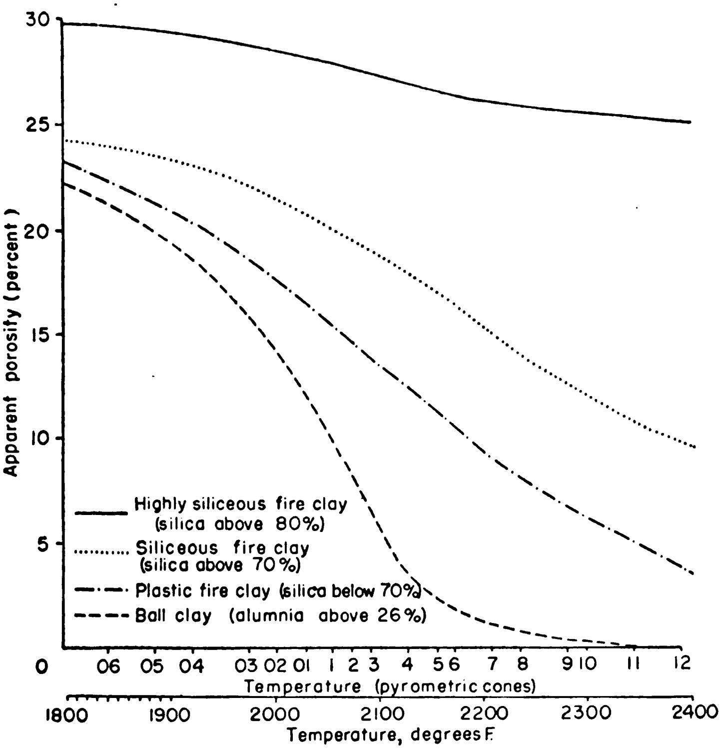

FIG. 15.—Average porosity-temperature curves characteristic of four types of Dakota formation clay.

centimeters, rather than on the basis of volume shrinkage. This produces curves easily comparable to the curves showing absorption and porosity changes. If percentage volume shrinkage were plotted on an inverted scale the effect would be the same.

Within the temperature range given volume change shows less uniformity, even within a single clay type, than the other properties. Some of the clay samples do not follow the characteristic flat S-curve, but rather a gradual decrease in the rate of volume change with change of temperature. Volume change curves for samples E1-52-3, E1-12-4, and E1-60-6 (Fig. 10) illustrate this most clearly. Many of the clay samples, however, show very little volume change over a long temperature range at the higher temperatures. This quality is valuable in that it permits wide variations of temperature in commercial firing, and in the case of refractories prolongs the usefulness of the installation.

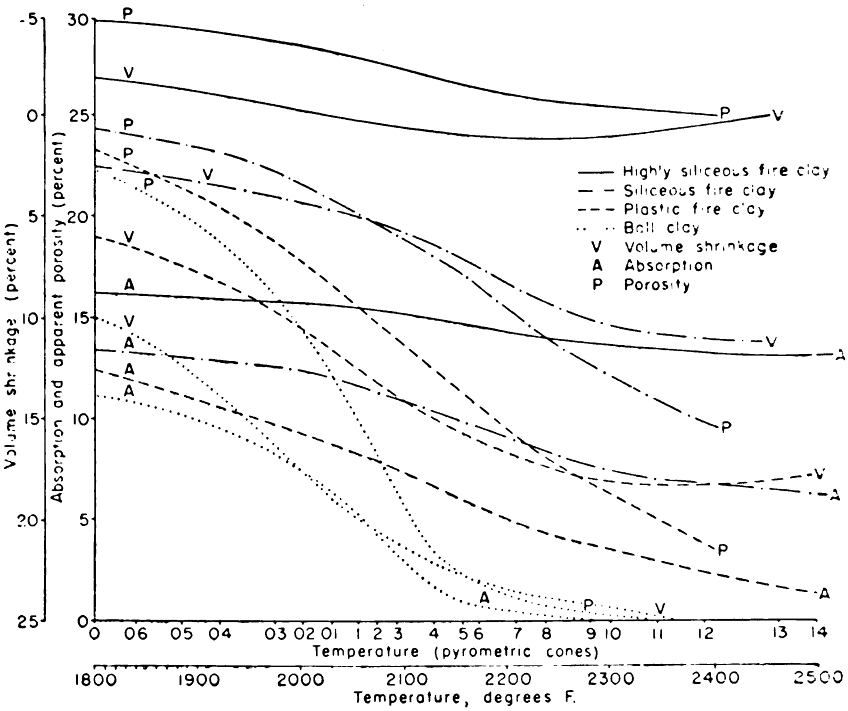

Fig. 16.—Graphs showing relationships of average absorption-temperature, porosity-temperature, and shrinkage-temperature data for four types of Dakota formation clay.

In the case of the curves showing change of absorption with increasing temperature the flat S-curve type predominates. If a greater temperature range were shown it is probable that all the curves would be nearly flat again in the higher range. The leveling off of absorption changes in the higher temperature range is highly desirable because this property in a clay (long firing and vitrification range) simplifies the production of uniform ware, and permits more nearly complete vitrification. This leveling off in the upper temperature range is especially pronounced in the case of samples El-52-3, O-38-4, W-5-5, C-12-B, El-85-4, TC-2-10, TC-2-1 (Fig. 12).

Inasmuch as both volume change and absorption are used in the calculation of apparent porosity, the curves showing the changes of this property with increasing temperature are an approximate average of volume change and absorption (Figs. 14, 15). The relationship of absorption, apparent porosity, and volume shrinkage to temperature of firing all four types of Dakota formation clays is shown graphically in Figure 16.

Minor irregularities in the data on all the fired properties are due to a number of complicating factors, such as differences in the ratio of illite to kaolinite clay minerals, iron content, and particle size. Sudden increases in volume, absorption, and apparent porosity after reaching a minimum are due to overfiring, usually resulting in bloating and a vesicular structure. This sudden change in the direction of the curves is particularly noticeable in the case of sample W-1-2 (Figs. 10, 12).

DARK BUFF TO RED-FIRING CLAYS

The Dakota formation clay which fires to dark buff or red differs from the clay firing to lighter colors only in the percentage of iron compounds which it contains. The complete range of types into which the white- to buff-firing clays were divided could be equally well applied to the clays firing to darker colors, although the terms "kaolin" and "ball clay" are never used to describe the dark-firing clays, and the term "fire clay", although not restricted to clay firing to the lighter colors, is seldom applied to dark buff- or red-firing clay. These restrictions in terminology are determined by the type of product which can be manufactured from the clay, rather than by differences in the physical and chemical properties of the clays other than the variation in content of iron oxides. The fired color of a bed of clay which is otherwise identical may vary laterally from white or buff to dark buff or red. This has been demonstrated in the laboratory by the removal of a large portion of the hematite or limonite from the red-firing facies by screening and magnetic separation, thereby changing it to a light-firing clay identical to the naturally light-firing facies.

The colors which the clays have when fired have a much greater range than is implied by the term "dark-buff- to red-firing." For example, it is common for a clay to fire to a pink at low temperatures and dark buff at higher temperatures, or to red at low temperatures and brown at higher temperatures. Tints of orange and lavender also occur. In fact, the colors, have an almost infinite variety. No two samples fire to exactly the same color, and the color of each fired sample varies with the temperature.

At least three-fourths of the total thickness of the Dakota formation is clay, and approximately two-thirds of the clay, or one-half of the total thickness of the formation, is dark buff- to red-firing. On outcrops or on the face of pits the darker firing clay is seldom uniform in color. Most commonly it is some tone of gray with red mottling or irregular splotches in which the coloring agent is hematite. Yellow colors, due to the presence of limonite, are also of common occurrence. Yellow mottling or splotching is usually found interspersed with the red. Yellow coloring, but very little red, occurs on oblique or nearly vertical joints throughout the thickness of the Dakota formation, but is especially characteristic of the Janssen clay member. Lavender tints are not uncommon in gray clay which is mottled with red and yellow. Small veinlets of these three colors, in some cases forming a dendritic pattern, also commonly occur in nearly white or light-gray clay which is mottled with red and yellow.

In any case, the parts of the clay which are not stained by iron compounds fire to a light color. In fact, the gray part of a mottled clay is more likely to fire to a very light color than a clay which is solid gray, indicating that the iron compounds in the red and yellow mottled clay are either concentrated or have not been disseminated.

Location and Occurrence of Samples Described

The dark buff- to red-firing clays described in this report were sampled in seven counties. The counties in which the samples were taken and the index numbers of the locations are: Cloud County, C-28; Ellsworth County, El-32; Hodgeman County, H-1; Russell County, R-6; Republic County, RP-8; Saline County, S-4; Washington County, W-16 (Pl. 1).

(C-28) Location C-28 is a few hundred yards west of the city limits of Miltonvale, Cloud County, adjacent to the right-of-way of the Santa Fe Railroad, and less than 0.25 mile east of a natural gas pipe line.

The same beds of clay sampled at C-28 were also sampled about 0.5 mile south at a location given the index number C-4. Similar beds of clay, in some cases occurring at the same horizon, were also sampled at locations C-12, C-13, C-14, C-15, C-16, C-24, C-29, C-30, and C-48. Sample C-12-B (location C-12) and sample

C-29-3 (location C-29) have been described under plastic fire clay and siliceous fire clay.

Measured section of pits from which sample C-28-3 was taken, S½ sec. 18, T. 8 S., R. 1 W., Cloud County.

Bed No.			Thickness, feet
	Dakota formation		
	Terra Cotta clay member		
	Soil and residual		0.7
4.	Clay, very silty to sandy, gray and buff with red and yellow mottling; contains much granular hematite and some concretionary limonite		12.3
3d.	**Clay, plastic, lavender and gray with red mottling and a small amount of yellow**		**5.4**
3c.	**Clay, slightly silty, light gray with red mottling**		**1.9**
3b.	**Clay, plastic, gray with lavender, red, brown mottling**		**7.2**
3a.	**Clay, silty, lignitic, dark gray**		**1.2**
	Total thickness of bed 3	**15.7**	
2.	Clay, slightly silty, gray with red-brown and lavender mottling; contains two thin irregular lenses of sandstone		3.6
1.	Clay, silty, gray and some yellow with brownish tan mottling		5.4
	Total thickness of measured section		37.7

Bed 4 of location C-28 was not sampled but probably would fire to a dark red, with darker spots due to the hematite. Bed 1 is a red-firing clay which does not differ greatly from bed 3. It is probable that an attractive face brick could be made from the entire thickness of beds exposed at this location. The small amount of sand present would be beneficial rather than harmful.

Division (a) of bed 3 is 3.5 feet thick where exposed in a pit excavated about 200 yards northwest of the measured section shown, and fires to a cream color.

(El-32) A total of 17 pits was excavated at location El-32, exposing beds totaling more than 145 feet in thickness. Of this total thickness more than 125 feet is clay.

Bed A is a composite bed made up of 11 beds which were sampled separately, and combined by mixing in proportion to the thickness of beds. Two beds of sandstone, totaling 6.2 feet in thickness, were omitted from the composite bed A. The total thickness of clay beds included in bed A is 95 feet, the thickest single bed of clay tested from samples taken in the Dakota formation.

More than three-fourths of the entire thickness of the Terra Cotta clay member was exposed in the 17 pits excavated at this location. At several other locations in the same Terra Cotta area all or a portion of the same stratigraphic section was exposed. These locations were listed and some cases discussed under location El-2 (siliceous fire clay) and location TC-2 (siliceous fire clay and highly siliceous fire clay).

Measured section of pits from which sample El-32-A was taken, Cen. N¼ sec. 16, T. 15 S., R. 6 W., Ellsworth County.

Bed No.			Thickness, feet
	Dakota formation		
	Terra Cotta clay member		
	Soil and sandy residual		1.7
17c.	Clay, light gray, and sandstone yellow and gray, in alternating thin beds		3.5
17b.	Clay, plastic, yellow and gray banded		3.0
17a.	Sandstone, yellow, and clay, gray, in alternating thin beds		2.2
	Total thickness of bed 17	8.7	
16.	Sandstone, medium to fine-grained, yellow to buff; contains a 2 to 4 inch band of concretionary hematite in a clay matrix		11.4
15.	Clay, plastic, yellow; contains bands of concretionary limonite		1.6
	Top of Bed A		
14.	**Clay, plastic, gray and yellow in alternating beds with concretionary limonite in yellow**		**4.4**
13.	Sandstone, gray, yellow, and brown; contains an 8-inch irregular band of clay and balls of clay toward bottom; bottom and top of bed are uneven and bed is apparently not continuous (not included in bed A)		4.2
12b.	**Clay, plastic, gray with some yellow stain**		**3.0**
12a.	**Clay, plastic, light gray with dark red mottling and some yellow stain; red portion is highly hematitic**		**4.0**
	Total thickness of bed 12	**7.0**	
11.	**Clay, plastic, light gray with moderate amount of red mottling**		**7.7**
10c.	**Clay, plastic, light gray with highly hematitic dark red mottling**		**10.4**
10b.	**Clay, plastic, yellow, gray, and red; contains yellow and red mottled hard "claystones" rimmed concentrically with selenite**		**3.4**

10a.	**Clay, plastic, light gray with a moderate amount of red mottling**		**4.0**
	Total thickness of bed 10	**17.8**	
9.	**Clay, plastic, dark gray with small amount of red mottling; contains a few small crystals of selenite**		**9.0**
8.	**Clay, plastic, light gray with red mottling and red in irregular vertical streaks and red and lavender in fine dendritic veining; contains a trace of selenite**		**14.8**
7.	**Clay, slightly silty to plastic, light gray and yellow with red mottling; contains granular hematite**		**10.7**
6d.	**Clay, plastic, nearly white with slight amount of pink and yellow stain**		**2.7**
6c.	**Silt, lignitic, "ash gray"; contains some concretionary limonite**		**0.5**
6b.	**Sandstone, clayey, fine-grained, gray**		**0.9**
6a.	**Clay, plastic, gray with some yellow**		**3.2**
	Total thickness of bed 6	**7.3**	
5.	Sandstone, massive, clayey, fine-grained, yellow; probably not continuous (not included in bed A)		2.0
4c.	**Clay, plastic, light gray with slight amount of red mottling**		**1.9**
4b.	**Clay, gray, with some irregular clayey sandstone**		**1.5**
4a.	**Clay, plastic, gray with very slight amount of pink and yellow stain**		**4.9**
	Total thickness of bed 4	**8.3**	
3.	**Clay, fairly plastic, gray; contains thin bands of clayey yellow sandstone**		**4.6**
2.	**Clay, silty, light gray, with very slight amount of yellow stain**		**3.5**
	Bottom of Bed A—Total thickness of bed A, 95.0 feet		
1b.	Clay, plastic, gray with brown, red, lavender, and yellow mottling; contains a thin limonitic sandstone at bottom		3.3
1a.	Clay, plastic, gray with red mottling		3.0
	Total thickness of bed 1	6.3	
02.	Clay, slightly silty, gray with a slight amount of yellow and a 2-foot band near middle containing a small amount of pink and red coloring; contains small pellets of limonite and hematite		12.1
01.	Clay, gray, alternating with thin irregular bands of concretionary limonitic sandstone		4.0
	Total thickness of section measured		147.1

Bed 1, which is a pink- to dark buff-firing clay, and bed 02, which is a buff-firing clay, should have been included in the combination of beds making up bed A. They were not included because the combination was made up before firing the test bricks made from these clays. Beds 01 and 02 were sampled from clays excavated later than those from which beds 1 to 17 were sampled. Inasmuch as the inclusion of beds 1 and 02 would not have changed the character of bed A, a total thickness of 113.4 feet of pink- to dark buff-firing clay is available at this location.

The fired colors of the individual beds are: 02, buff; 1, dark buff; 2, ivory to cream; 3, buff; 4, buff; 6, buff; 7, red; 8, pink to dark buff; 9, buff; 10, red; 11, red; 12, red; 14, buff.

The pits from which the beds were sampled at this location were spaced along a gentle slope. The horizontal distance from the bottom to the top pit was nearly 0.25 mile. The overburden at no place exceeds 4 feet in thickness, and in most places is less than 2 feet.

(R-6) Data on samples R-6-9 and R-6-11 have been presented and location R-6 has been discussed in detail under ball clay. Other locations in the general area which are described in this report are L-38 (plastic fire clay), and L-39 (siliceous fire clay).

Measured section of pits from which sample R-6-5 was taken, NE¼ NW¼ sec. 25, T. 12 S., R. 11 W., Russell County.

Bed No.			Thickness, feet
	Dakota formation		
	Janssen clay member		
12.	Silt to fine sandstone		3.9
11.	Clay, plastic, gray to dark gray (ball clay)		5.7
10.	Clay, plastic, yellow and gray		2.0
9.	Clay, plastic, gray to nearly black with some yellow (ball clay)		7.8
8.	Clay, silty, light gray		4.2
7.	Sandstone and silt, clayey, gray and yellow		2.0
6b.	Clay, lignitic, plastic, gray		1.1
6a.	Clay, plastic, gray with red and yellow mottling		5.5
	Total thickness of bed 6	6.6	
5b.	**Clay, plastic, gray with some fine mottling of red and yellow; contains scattered very small crystals of selenite**		**7.2**
5a.	**Clay, plastic, dark gray with a small amount of fine red mottling; contains a few very small crystals of selenite**		**4.0**
	Total thickness of bed 5	**11.2**	
	Terra Cotta clay member		
4-1.	Described in detail under ball clay		27.2
	Total thickness of section measured		70.6

Bed 2 is a cream-firing clay; bed 3 is a red-firing clay; and beds 4 and 6 fire to colors ranging from pink to dark buff. A combination of beds 2 to 6, inclusive, makes available a total thickness of 38.3 feet of pink- to dark buff-firing clay very similar to bed 5.

(RP-8) More than one-third of the total thickness of clay beds sampled in Republic County fired to colors varying from ivory to buff. Therefore, sample RP-8-2, here described, is not to be considered typical of the Dakota formation clay in that county, but as an excellent example of a red-firing clay.

Clay beds occurring at approximately the same stratigraphic position and similar in character were sampled at location RP-10, 1 mile northeat of RP-8, and at location RP-11, 0.75 mile east. At the latter location a 13-foot bed of buff-firing clay was sampled.

Measured section of pits from which sample RP-8-2 was taken, Cen. W ½ sec. 11, T. 4 S., R. 1 W., Republic County.

Bed No.		Thickness, feet
	Dakota formation	
	Terra Cotta clay member	
3.	Sandstone, hematitic, very dark brown, weathered	1.9
2c.	**Clay, silty, buff and gray**	**2.4**
2b.	**Clay, slightly silty, yellow, gray, and brownish-red to red mottled**	**6.8**
2a.	**Clay, slightly silty, light gray with pinkish red, yellow, and some lavender mottling**	**12.7**
	Total thickness of bed 2	**21.9**
1.	Silt, clayey, light gray with irregular bands of bright yellow; contains some soft hematite and limonite	6.9
	Total thickness of section measured	30.7

In the pits from which sample RP-8-2 was taken the overburden consists entirely of weathered sandstone having a maximum thickness of 1.9 feet. In another pit excavated about 50 feet to the east, about 9 feet of Pleistocene terrace deposits covers the Dakota clay. These deposits, however, are seemingly not extensive.

(S-4) Location S-4 is approximately mid-way between Brookville, Saline County, and the western limits of the Terra Cotta area in Ellsworth County. Samples were taken at several locations in this area and included beds from both the Kiowa shale formation and the Dakota formation. Ellsworth County locations in the Terra Cotta area are listed in the discussions of locations TC-2 and El-2. The Saline County locations include S-2, S-8, S-9, and S-10.

The topography of this area is unusually rugged, having a maximum relief of 400 feet with differences of elevation of as much as 200 feet in 0.125 mile.

Measured section of pits from which samples S-4-1 and S-4-4 were taken, NW¼ SE¼ sec. 18, T. 15 S., R. 5 W., Saline County.

Bed No.			Thickness, feet
	Dakota formation		
	Terra Cotta clay member		
11.	Sandstone, medium to fine-grained, cross-bedded, red to red-brown (thickness in pit exposure)		2.3-4.6
10.	Clay, plastic, gray; contains thin lenses of yellow sandstone		5.0-7.3
9.	Clay, plastic, gray		4.5
8.	Clay, slightly silty, gray, and short lenses of yellow sandstone having a maximum thickness of 1.3 feet		2.3
7.	Sandstone, clayey, fine-grained, massive, friable, cream to nearly white; contains a few limonitic concretions		5.2
6.	Clay, slightly silty, gray; contains a lenticular sandstone having a maximum thickness of 4 inches		4.6
5b.	Sandstone, fine to medium-grained; contains thin bands of gray clay		6.8
5a.	Silt, clayey, friable, gray to yellow		5.0
	Total thickness of bed 5	11.8	
4h.	Clay, plastic, gray and yellow		4.0
4g.	Clay, plastic, yellow and red		2.0
4f.	Clay, plastic, gray with red mottling and slickensides on oblique joints		7.0
4e.	Clay, plastic, yellow with red mottling		1.8
4d.	Clay, plastic, gray with red mottling		3.6
4c.	Clay, plastic, red and yellow		3.8
4b.	Clay, silty, red and yellow		1.0
4a.	Clay, plastic, yellow, red, and gray		5.3
	Total thickness of bed 4	28.5	
3.	Clay, plastic, light gray		3.0
2.	Sandstone, fine-grained, massive, yellow to gray; contains ellipsoidal concretions of "quartzite"		4.0
1.	Clay, plastic, dark gray, alternating in thin laminae with white silt and fine sand		6.0
	Total thickness of measured section		79.5

Beds totaling 137.2 feet in thickness were exposed in pits excavated at this location. The lower 57.7 feet, not given in the measured section above, consists of beds in the Kiowa shale formation.

Bed 1 is here considered the lowermost bed of the Dakota formation, although normally it would be considered the uppermost bed of the Kiowa shale, inasmuch as the base of the "quartzite" containing sandstone, bed 2, arbitrarily has been designated as the bottom of the Dakota formation (Plummer and Romary, 1942). When the beds underlying this sandstone are examined critically, however, we have found in many places beds which are lithologically intermediate in character between those of the Kiowa shale and the Dakota formation. Bed 1 of location S-4 is typical, both in thickness and appearance, of the bed or beds which were deposited under environmental conditions intermediate between the marine and continental. The fired color of this clay is brown, indicating that the dominant clay mineral present is illite.

(W-16) The clay beds sampled at location W-16 probably are not sufficiently uncommon to warrant shipment of the clay to distant plants, but they could be utilized very economically by a plant on the site, particularly in the manufacture of face brick. Fired colors having varying tones of buff, lavender, and red could be obtained. The location is less than 0.5 mile west of the town of Morrowville, Washington County, less than 1 mile west of Kansas highway 15, and about 0.25 mile south of the Frisco Railroad tracks.

Beds almost identical to those at location W-16 were also sampled at location W-43, which is a few hundred yards southeast of the city limits of Morrowville. At both locations the overburden is no more than a few feet thick over areas large enough to supply a brick plant for many years.

Measured section of pits from which sample W-16-1 was taken, SE¼ SE¼ sec. 27, T. 2 S., R. 2 E., Washington County.

Bed No.		Thickness, feet
Pleistocene(?)		
	Clay, silty, gray	3.5
Dakota formation		
	Terra Cotta clay member	
5.	Clay, plastic, red, cream, and gray; may not be in place	2.0
4c.	Clay, plastic, red with some gray; contains a small amount of selenite	2.7
4b.	Clay, plastic, brown and gray	2.0
4a.	Clay, slightly silty, gray with some yellow and red	1.9
	Total thickness of bed 4	6.6

3.	Clay, fairly plastic, gray to dark gray with a small amount of red mottling and some yellow stain on joints	8.8
2.	Clay, slightly silty, light gray and some lavender and yellow with red mottling and red in irregular vertical streaks and red and lavender in fine-veined to dendritic pattern	7.3-8.0
1.	**Clay, fairly plastic, gray to light gray and some lavender with red mottling and some yellow on slickenside joints and also some red and lavender in fine-veined or dendritic pattern**	**13.1-13.8**
	Total thickness of measured section	41.3-42.7

Bed 2 of this location has the same range of fired colors as bed 1, pink to dark buff. Bed 3 is a buff-firing clay and bed 4 a red-firing clay. A combination bed composed of beds 1, 2, and 3 fires to lavender tints at cone 04.

(H-1) The red-firing or dark buff-firing clay beds occurring at other locations described in this report have been, for the most part, mixed types; that is to say, the clay as exposed on the face of pits has been gray with areas of red, yellow, or lavender mottling or splotches. Sample H-1-01, from location H-1, in contrast, is uniformly brownish red with only a few gray spots, and is probably typical of the red portion of all variegated colored clay beds in the Dakota formation.

The measured section described is a composite from sections measured in two series of pits about 100 feet apart. Beds 01 to 04 were measured from the west series and beds 4 to 8 from the east series of pits.

Outcrops of clay similar to those sampled at location H-1 were found on the bluffs southeast of the flood plain of Buckner Creek, extending from a point about 1 mile northeast of location H-1 to nearly 3 miles southwest of the location. The clay beds of this area are discussed in greater detail under plastic fire clay.

Measured section of pits from which sample H-1-O1 was taken, SE¼ SW¼ sec. 24, T. 22 S., R. 22 W., Hodgeman County.

Bed No.		Thickness, feet
	Dakota formation	
	Janssen clay member	
8.	Clay, silty, gray and some yellow	1.6
7.	Clay, very silty to fairly plastic, light gray with limonitic joint filling	4.6

6.	Clay, mostly plastic, gray to dark gray (plastic fire clay)	5.4
5.	Clay, plastic, yellow and light gray; contains hematite and limonite pellets	4.0
4.	Clay, very silty, lignitic, gray to dark gray with some yellow	4.7
04.	Clay, very silty, light gray; contains aggregates of limonite or siderite pellets	2.6
03.	Siltstone, buff, gray, and some yellow; contains aggregates of hematite pellets in abundance	1.5
02.	Clay, silty, light gray and some yellow with oblique joints containing limonite; contact with bed 01 is uneven	2.3
	Terra Cotta clay member	
01.	**Clay, slightly silty, brownsih red, with a small amount of gray; contact with bed 02 is uneven; bottom of bed is not exposed**	5.3
	Total thickness of measured section	32.0

A considerable thickness of red and yellow mottled clay is exposed down-slope from bed 01, but the depth to which this bed extends below the bottom of the measured section was not determined.

Ceramic slag of excellent quality was produced from bed 01 by firing in a rotary kiln to 2,225° F.

Mineralogic Properties

The Dakota formation clay which fires to light colors differs from the clay firing to dark buff or red only in that a higher percentage of iron-containing minerals is present in the latter. The most common of these minerals, hematite and limonite, are the source of the red and yellow colors in the clay. Ilmenite and siderite are also present, but usually in smaller amounts. Fairly large nodules or crystals of pyrite are not uncommon, but finely disseminated pyrite is probably of very rare occurrence.

In a few cases it is apparent that illite, a clay mineral in which iron is a constituent of the molecule, is present in sufficient amounts to produce a darker color in the fired sample. The fired color of clay of this type is likely to be of a somewhat dingy tint of orange or brown, rather than clear pink, red, or buff. The dominant clay mineral in the Dakota formation clay samples examined is with but few exceptions kaolinite. In such clays the iron minerals oxidize to hematite on firing. if not originally present as hematite. Furthermore, the iron minerals are entirely independent of the clay or quartz particles, and are relatively coarse-grained, probably of the same order of magnitude as the clay and quartz particles themselves, whereas in the illite clay, the iron in the clay molecule is not readily oxidized so that a portion is present in the fired clay as the gray ferrous oxide. Furthermore, particles of the iron oxides are in part submolecular in size, and in the presence of potassium, another constituent of illite, are readily fused into the yellow silicate of iron. The coloring effects are further complicated by the presence of sulfur compounds such as gypsum or pyrite. In this case the iron silicate has a brown color. Sample S-4-1 is a brown-firing clay that probably belongs in this class.

Chemical Properties

The mineral content of clays determines the chemical composition. For this reason the preceding section on mineralogical properties is also descriptive of the chemical properties. The chief difference between the clays firing to lighter colors and the dark buff to red-firing clays is the higher percentage of iron-bearing compounds in the darker-firing clays. Chiefly, the iron is present in the form of the ferric oxide or hydroxide, with minor proportions of iron silicates and iron sulfide. The iron-containing minerals are reported in the chemical analyses as ferric oxide (Fe_2O_3). It will be noted that the alumina to silica ratio is lower in the darker-firing clays than in those firing to lighter colors, but that the R_2O_3 to silica ratio is about the same. This would indicate the possibility that the iron replaces a portion of the alumina in the case of the more ferruginous clays (Table 19).

Ceramic and Other Physical Properties

The forming, drying, and firing properties of the Dakota formation clays firing to darker colors differ but little from those firing to lighter colors. The higher percentage of iron oxide present in the dark-buff- to red-firing clays no doubt lowers the maturing temperatures somewhat, but within the usual range of commercial firing temperatures the percentage of either free silica or illite clay minerals has a much more marked effect than the iron. The

TABLE 19.—*Chemical composition of dark buff- to red-firing clays described in this report*

(Analyses by Raymond Thompson and Russell Runnels)

	Constituents, percent								
Lab. No.	Silica (SiO_2)	Alumina (Al_2O_3)	Iron oxide (Fe_2O_3)	Titanium oxide (TiO_2)	Calcium oxide (CaO)	Magnesium oxide (MgO)	Potassium and sodium oxides (K_2O Na_2O)	Ignition loss	Total determined
C-28-3	65.20	18.79	5.66	....	0.48	0.46	2.25	6.49	99.33
El-32-A	67.00	21.11	3.20	0.20	0.38	0.85	1.15	5.86	99.75
H-1-01	59.13	15.30	9.48	4.66	0.48	0.91	3.54	5.92	99.42
R-6-5	58.65	21.22	4.27	3.91	0.98	0.53	2.40	7.55	99.51
RP-8-2	62.00	20.19	5.46	2.86	0.41	0.55	2.41	6.50	100.47
S-4-1	75.76	*13.72	2.88	....	0.45	0.38	....	5.23	98.42
S-4-4	67.83	*17.05	3.25	....	0.71	0.80	....	6.84	96.48
W-16-1	65.44	21.05	3.54	0.40	0.78	2.17	0.60	6.08	100.06

*Includes TiO_2

iron compounds, of course, largely account for the differences in color of both the raw and the fired clay.

In selecting clay samples to be included in Table 20 an attempt was made to include as great a variety of buff- to red-firing clays as possible, and at the same time obtain geographical distribution so that the entire outcrop area would be represented. Highly siliceous clays are rare in the darker firing clays of the Dakota formation, and none was included in this report.

In Table 20 the clays tested have a firing range ranging from 6 cones to 16 cones, with no abrupt changes in shrinkage or absorption within this range. In many cases almost no change will occur over a range of two or three cones.

The fired color of some of the clays varies greatly within the firing range. The majority of about 900 darker-firing clays tested fired to some shade of pink at lower temperatures (cone 07 to cone 03). Those having a relatively high iron content fired red or brown at higher temperatures, whereas those with a smaller content of iron fired to tans and buffs at the higher temperatures. Near the maximum temperature of firing, which ranged from about cone 2 to about cone 16, many of the test bricks turned to dark brown or dark gray. In general the reds obtained on firing Dakota formation clays are not as clear and brilliant as those ob-

TABLE 20.—*Data on ceramic tests of dark buff- to red-firing clays*

Plastic and Dry Properties

Sample No.	Dry color	Water of plasticity percent	Shrinkage water, percent	Pore water, percent	Volume shrinkage, percent	Calculated linear shrinkage, percent	Time required to slake 1" cube, minutes	Modulus/ Rupture lbs. per sq. in.
C-28-3	brown red	22.6	10.6	12.0	21.8	6.8	30	644
El-32-A	red	20.0	10.9	9.1	22.5	7.0		328
H-1-01	red brown	23.4	11.2	12.2	22.4	7.0	17	604
R-6-5	pink gray	25.6	15.1	10.5	31.0	9.4	240	377
RP-8-2	red	23.8	11.1	12.7	22.5	7.0	39	326
S-4-1	gray	20.8	7.0	13.8	13.5	4.3	38	199
S-4-4	light red	21.8	10.5	11.3	21.7	6.8	87	438
W-16-1	red	23.6	11.1	12.5	22.3	6.9	92	488

Fired Properties

Sample No.	Fired to cone	Fired color	Volume shrinkage, percent	Calculated linear shrinkage, percent	Absorption, percent	Apparent porosity, percent	Apparent specific gravity	Bulk specific gravity	Hardness	Best firing range (pyrometric cone)
C-28-3	05	pink buff	10.3	3.6	7.8	16.7	2.58	2.15	H	07 to
	5	orange	12.5	4.4	5.4	11.8	2.50	2.20	H	5+
El-32-A	06	pink	4.1	1.4	11.6	23.3	2.61	2.00	S	05 to
	5	dark buff	11.8	4.1	6.0	13.1	2.52	2.19	H	8
	8-9	red tan	11.1	3.9	5.2	11.2	2.42	2.15	H	

H-1-01	04	red	11.2	3.9	7.9	16.7	2.55	2.12	S	06 to
	3	red	20.0	7.2	2.9	6.8	2.50	2.33	H	3
R-6-5	03-04	brown	17.9	6.4	5.9	13.1	2.54	2.21	H	07 to 2 (?)
RP-8-2	05	red	14.2	5.0	6.2	13.9	2.58	2.22	S	07 (?)
	6	red	19.2	6.9	1.0	2.3	2.38	2.33	H	to 6
S-4-1	06	brown	*1.1+	0.4+	14.8	26.7	2.46	1.80	S	03 (?)
	6	brown	18.4	6.6	4.0	8.9	2.44	2.22	H	to 6
S-4-4	05	dark orange	11.1	3.9	7.0	15.4	2.60	2.20	H	07 (?)
	6	red	17.9	6.4	1.8	4.1	2.41	2.31	H	to 6
W-16-1	03-04	pink buff	10.5	3.6	9.0	18.8	2.59	2.10	S	
	4	dark buff	13.3	4.7	6.0	13.1	2.53	2.20	H	05 to
	8	dark buff	13.0	4.5	4.8	10.5	2.46	2.20	H	11
	11	gray buff	17.6	6.3	2.5	5.7	2.44	2.30	H	

*Plus sign indicates expansion

tained with the shales of Pennsylvanian age which are used in all the brick plants of southeastern Kansas. The browns and dark buffs, however, are usually attractive.

Many of the darker firing clays are sufficiently refractory to be classed as fire clays—that is, they have a pyrometric cone equivalent of cone 19 or higher. Brick made from almost any clay safely could be used for the construction of kilns in which structural clay products made from the same clay were fired. The clays firing to dark buff make excellent low temperature refractories due to the long firing and vitrification range, high transverse and compressive strength, high resistance to abrasion, and fair resistance to heat shock.

Some of the darker-firing clays, like the lighter-firing varieties, have an excessive drying and firing shrinkage for use in the manufacture of structural clay products. In such instances sand or grog, or a more open clay would have to be added. Sample number R-6-5 is an example of this type. With few exceptions red-firing clay, fine sand, and siliceous open clay are found associated with the plastic high-shrinkage clay.

KIOWA SHALE

Where present in Kansas the Kiowa shale formation underlies the Dakota formation (Plummer and Romary, 1942). Typically, the Kiowa shale is dark gray, thinly laminated, and extremely plastic, and contains well-formed fairly large crystals of selenite, ironstone concretions, and some pyrite. The ironstone concretions usually occur as fairly continuous bands in the shale.

Thin, evenly bedded fine-grained sandstone or silt deposits, and thin beds of cone-in-cone gypsum or limestone are also common in the Kiowa shale formation.

The shale beds are typical marine deposits. Many samples examined contained imprints of marine shells. On the outcrop Kiowa shale beds cannot in all cases be distinguished from the Graneros shale except by stratigraphic position. The ceramic properties of the shale samples taken from these two formations are almost identical.

Location and Occurrence of Samples Described

(El-22) Beds totaling 180 feet in thickness were exposed in the 18 pits excavated at location El-22. The pits were excavated on the face of a steep bluff which in some places rises almost vertically from the north bank of Smoky Hill River (Pl. 5B). The measured section given below is particularly interesting in that it describes a considerable thickness of beds typical of both the Kiowa shale and Dakota formations.

Measured section of pits from which sample El-22-6 was taken, near Cen. S½ sec. 1, T. 16 S., R. 7 W., Ellsworth County.

Bed No.			Thickness, feet
	Dakota formation		
	Terra Cotta clay member		
27.	Sandstone, medium-grained, cross-bedded, yellow to brown, with sharply convex bottom—a channel filling		15.8
26.	Clay, silty, yellow to light gray		3.0
25.	Silt, clayey to silty clay, gray with slight yellow stain; contains a few particles of lignite		5.2
24.	Silt to fine sandstone, gray with yellow to buff banding; contains streaks of clay		4.4
23.	Sandstone, fine-grained, lensed or interfingered with gray fairly plastic clay to silt		8.3
22b.	Clay, fairly plastic, yellow and light gray; contains limonite pellets		1.2
22a.	Clay, silty, yellow, red, and some gray mottled; contains hematite and limonite pellets		0.8
	Total thickness of bed 22	2.0	
21.	Clay, plastic to slightly silty, very light gray with some yellow and lavender mottled pink		4.1
20.	Clay, smooth, plastic, very light gray		2.2
19.	Clay, silty, gray, with yellow joint stain; contains leaf fossils		2.6
18.	Silt to very fine sandstone, clayey, light gray with some yellow stain; contains thin beds of gray clay		12.7
17.	Clay, slightly silty, creamy gray		1.0
16.	Sandstone, medium-grained, very light gray to cream with a few yellow patches		7.7
15.	Clay, gray, and sand, yellow, in thin alternating beds		2.0
14b.	Clay, plastic, light gray mottled in red with some purple and yellow		10.4
14a.	Clay, rather silty, gray with some lavender and yellow and mottled with dark red which is hard and highly hematitic		5.0
	Total thickness of bed 14	15.4	
13b.	Clay, very silty, gray, yellow, and reddish brown; contains hematite and limonite pellets		1.6
13a.	Clay, very silty to silt, gray and some yellow		3.0
	Total thickness of bed 13	4.6	

12.	Silt, gray and yellow with paper-thin streaks of clay and sand and one 0.6 foot zone of yellow sand	3.6
11.	Sandstone, fine-grained, very light creamy gray with a small amount of yellow stain; cross-bedding dips southeast or east	10.8
10.	Clay, fairly plastic, gray with a small amount of red and yellow mottling	2.6-3.6
9d.	Clay, slightly silty, lignitic, gray	0.8-1.8
9c.	Clay, slightly silty, light gray with some yellow-brown stain and a small amount of red and yellow mottling; has pronounced conchoidal fracture and breaks out in round balls as much as 2.0 feet in diameter	3.7
9b.	Clay, plastic, lignitic, very dark gray	1.5
9a.	Clay, silty, gray	0.8
	Total thickness of bed 9	6.8-7.8
8.	Clay, slightly silty, gray to dark gray, with irregular patches or chunks of limonitic fine sand	4.2
7.	Silt to fine sandstone, dirty buff and some brown, in thin horizontal beds with ironstone bands; contains "quartzite" concretions	5.8
Kiowa shale formation		
6.	**Clay-shale, plastic, gray to dark gray with some brown and yellow stain; contains selenite crystals, clay-ironstone bands, and cone-in-cone gypsiferous limestone; shale has acid taste**	21.1
5.	Silt to fine sandstone, micaceous, gray with a small amount of yellow stain	5.4
4.	Shale, plastic to silty, dark gray with much yellow and brown stain; contains 2 clay-ironstone bands and much selenite	4.1
3.	Sandstone, medium- to fine-grained, micaceous, buff, light yellow and brown, horizontally bedded, with ripple marks near top	11.7
2.	Sandstone, fine-grained, yellow, alternating in thin horizontal beds with gray silty clay	4.0
1.	Clay-shale, plastic, dark gray, with some yellow-brown stain; contains clay-ironstone bands and some selenite	7.0
	Total thickness of measured section	179.1

Although the beds of sandstone and silt are abnormally thick at this location and the clay beds proportionately thin, the lithological sequence is typical.

Beds 1 and 6 of Kiowa shale are red-firing. The clay beds sampled from the Dakota formation, listed with the fired colors, are as follows: bed 9, buff; bed 10, red; bed 14, red; bed 20, cream; bed 21, red; bed 25, buff.

(El-100) The shale sampled at location El-100 occurs in the lower part of the Kiowa shale formation. Permian beds outcrop near Langley, which is about 0.75 mile north of location El-100.

Measured section of pits from which sample El-100-3 was taken, NE¼ NE¼ sec. 34, T. 17 S., R. 6 W., Ellsworth County.

Bed No.			Thickness, feet
	Kiowa shale formation		
	Soil and residual		0.8
4.	Sandstone, medium-grained, yellow and brown		1.5
3b.	**Clay-shale, plastic, gray with some yellow stain; top half shows effect of weathering**		**5.0**
3a.	**Clay, shale, plastic, gray with considerable amount of yellow stain; contains bands of clay-ironstone concretions**		**5.0**
	Total thickness of bed 3	10.0	
2.	Clay shale, gray with streaks of yellow sand; contains much gypsum		2.5
1.	Clay shale, plastic, dark gray		1.5
	Total thickness of measured section		16.3

The owner of this clay deposit reports that a thickness of 20 feet of shale similar to and underlying bed 1 was found in a well dug a short distance south of the excavated pits.

(RE-2) Location RE-2 is 3.75 miles east of Crawford, Rice County. The beds exposed in the excavated pits are near the top of the Kiowa shale formation. The Kiowa-Dakota contact was not definitely placed, but a bed sampled at location RE-3, about 0.25 mile south of RE-2, is definitely a Dakota formation clay, and is but 20 feet above the top of bed 2 at location R-2.

Measured section of pits from which sample RE-2-1 was taken, NW¼ SE¼ sec. 3, T. 18 S., R. 6 W., Rice County.

Bed No.			Thickness, feet
	Kiowa shale formation		
2.	Shale to thin-bedded clay, silty, yellow and light gray with some thin streaks of limonitic sand		2.3-7.3
1b.	**Clay to clay-shale, plastic, gray with some yellow stain; contains three thin bands of concretionary limonite and some gypsum crystals**		**6.8**
1a.	**Clay-shale, plastic, dark gray; contains large euhedral crystals of selenite and some pyrite**		**2.0**
	Total thickness of bed 1	8.8	
	Total thickness of measured section		11.1-16.1

It is probable that bed 1, as sampled, represents only the upper portion of a shale bed of considerable thickness, but from the outcrops this could not be definitely established as a fact.

Mineralogic Properties

The dark plastic thinly laminated shale of the Kiowa formation is an extreme type of marine shale, which presumably in many cases is composed almost entirely of the clay mineral illite, with very little uncombined silica in the form of silt. Montmorillonite may be present in small amounts, but kaolinite is probably almost entirely lacking. Silty shale occurs in the Kiowa, but is not characteristic of the formation as is the silty clay of the Dakota. The striking differences in the ceramic properties of the clay or shale of two formations is due, however, to the fact that the clay minerals of the Kiowa shale are dominantly of the illite group, and those of the Dakota clay, are kaolinite.

According to Grim (1939) illite is not an individual clay mineral, but a group which includes the abundant and widely distributed clay minerals which are similar but not identical with muscovite. So-called "hydro-mica" and "sericite-like" material belong in this group. The general formula for members of the group may be written $(OH)_4K_y(Al_4.Fe_4.Mg_4.Mg_6)$ — $(Si_{8-y}.Al_y)O_{20}$. The mineralogic properties of the various types of clay are discussed in considerable detail in the first part of this report.

Due to the fact that iron, potassium, and magnesium are present in the molecule the illite shale vitrifies at low temperatures, and is not refractory. The orange, red, and brown color to which all illite shales fire is due to the iron which is a chemical constituent of the molecule. Accessory minerals present in the Kiowa shale include quartz, selenite, pyrite, and limonite. The selenite is conspicuously present in the form of euhedral crystals of fair size, also in needlelike crystals in the shale partings. It is probable that some of the selenite is secondary, having been formed by the chemical combination of calcium carbonate and sulfuric acid. The decomposition of pyrite produces sulfuric acid and hematite or limonite. Many of the Kiowa shale samples have an acid taste, indicating the presence of excess sulfuric acid, and the calcium carbonate of all marine shells deposited with the shale has been completely displaced leaving only an impression of the shell form.

Pyrite or marcasite occurs in the form of nodules and small crystals, some of which are probably microscopic in size and disseminated throughout the clay material.

That soluble salts are present in some samples of Kiowa shale is evidenced by the fact that the fired samples have a white scum, or a crystalline efflorescence on them. The salts are probably the magnesium and calcium sulfates, epsom salts and gypsum.

Beds of hematite, or hematitic clay-ironstone are of common occurrence in the formation, but the hematite characteristically does not occur as an intimate mixture with clay, as is the case with the clay of the Dakota formation. In the area investigated we found no red Kiowa shale.

Chemical Properties

An ultimate chemical analysis of a clay is a valuable, but by no means infallible index of its mineral content. The chemical composition, plus characteristic ceramic properties, reveals with considerable accuracy, however, the identity of the minerals dominant in a clay.

The chemical formula for illite, the most important constituent of the Kiowa shale, has been given in the discussion of mineralogic properties. Chemical analyses published by Grim and Bradley (1940, p. 243) of samples of illite clays are given in Table 21.

Although the percentage of K_2O is not constant in illite, 4 to 6 percent K_2O in a clay indicates that its chief constituent is illite.

TABLE 21.—*Chemical composition of three samples of purified illite*

(Analyses made under supervision of O. W. Rees, Chemist, Illinois State Geological Survey) (Grim and Bradley, 1940, p. 243)

Constituents	(1)	(2)	(3)
SiO_2	52.79	51.22	51.10
Al_2O_3	24.99	25.91	21.96
Fe_2O_3	4.68	4.59	6.38
FeO	1.10	1.70	1.65
MgO	2.70	2.84	3.91
CaO	0.09	0.16	1.73
Na_2O	0.20	0.17	0.03
K_2O	5.86	6.09	6.62
TiO_2		0.53	0.46
Loss on ignition	7.14	7.49	6.24
Total	99.55	100.70	100.08

TABLE 22.—*Chemical composition of Kiowa shales described in this report*
(Analyses by Raymond Thompson and Russell Runnels)

	Constituents, Percent								
Lab. No.	Silica (SiO_2)	Alumina (Al_2O_3)	Iron oxide (Fe_2O_3)	Titanium oxide (TiO_2)	Calcium oxide (CaO)	Magnesium oxide (MgO)	Potassium and sodium oxides (K_2O Na_2O)	Ignition loss	Total determined oxide
El-22-6	57.25	22.98	3.30	1.15	0.48	2.35	3.87	8.21	99.59
El-100-3	59.38	25.50	1.49	1.64	0.73	1.15	3.95	6.58	100.45
RE-2-1	59.66	19.44	3.18	1.97	1.35	3.02	4.25	7.58	100.43

In the analyses made on Kiowa shale samples the total percentage of alkalies is given, rather than Na_2O and K_2O separately. It is probably safe to assume, however, that the Na_2O content does not exceed 0.5 percent.

Ceramic and Other Physical Properties

The ceramic properties of the Kiowa shale are those characteristic of a fine-grained or easily disintegrated illite clay. These properties include high bond strength and high drying and firing shrinkages. These clays when fired to low temperatures form an extremely close-grained body which is difficult to oxidize completely, and therefore tends to bloat and crack. The addition of 50 percent grog, composed of the calcined sample or other inert material, largely eliminates this difficulty. The fired colors are usually orange red or red brown, but a few samples fired to a dark buff.

Although the Kiowa shale commonly has a fissile or laminated structure it has not been indurated sufficiently to prevent almost instantaneous slaking in water. In fact, the laminated structure in most cases is merely extremely thin bedding, with light-colored silt of almost microscopic thinness occurring on the bedding planes. The silt probably represents seasonal changes in deposition. If any part of the shale fails to slake in water it is commonly these extremely thin flakes of clayey silt. The clayey silt probably fails to slake because of silicification, which is described by Grim (1941) as cryptocrystalline silica occurring around the edge of quartz grains and disseminated through the clay-mineral flakes.

TABLE 23.—*Data on ceramic tests of Kiowa shale samples*

Plastic and Dry Properties

Sample No.	Dry color	Water of plasticity, percent	Shrinkage water, percent	Pore water, percent	Volume shrinkage, percent	Calculated linear shrinkage, percent	Time required to slake 1" cube, minutes	Modulus/ Rupture lbs. per sq. in.
El-22-6	greenish gray	31.4	19.3	12.1	37.8	11.3	25	471
El-100-3	yellowish gray	28.2	17.9	10.3	36.8	11.0	92	470
El-100-3 (50% grog)	gray	24.9	9.7	15.2	17.9	5.6		
RE-2-1	gray	35.4	21.0	14.4	41.0	12.1	19	1008
RE-2-1 (50% grog)	gray	26.3	11.1	15.2	20.2	6.3		378

Fired Properties

Sample No.	Fired to cone	Fired color	Volume shrinkage, percent	Calculated linear shrinkage, percent	Absorption, percent	Apparent porosity, percent	Apparent specific gravity	Bulk specific gravity	Hardness	Best firing range (pyrometric cone)
El-22-6	05	orange red	18.4	6.6	3.7	7.8	2.30	2.12	S	07-05
El-100-3	04	orange	12.1	4.2	9.3	18.6	2.47	2.01	S	05 to
(50% grog)	3	red	18.5	6.6	6.2	13.7	2.55	2.20	H	above
	7	red	18.6	6.6	5.4	11.9	2.50	2.20	H	7
RE-2-1	05	dark buff	17.2	6.1						05 to
RE-2-1 (50% grog)	04	dark buff	13.3	4.7	10.5	20.9	2.53	2.00	S	5 (?)

A comparison of the ceramic properties of the Kiowa shale with those of the Graneros shale and the shales of Pennsylanian age is given in the discussion of Graneros shale.

Data on ceramic tests of Kiowa shale samples are given on Table 23.

GRANEROS SHALE

The Graneros shale formation occurs above the Dakota formation and below the Greenhorn limestone (Plummer and Romary, 1942). Although beds of silt and fine-grained sandstone occur in the Graneros shale formation, the beds of gray to dark-gray clayey shale are the most conspicuous lithological feature of the formation. The shale beds of the Graneros are very similar in appearance and ceramic properties to those of the Kiowa shale. In general, the shales of both formations are typically marine in character. Considering the formations as a whole, however, there are slight but important differences. Thin beds of bentonite and one thin bed of kaolin are found in the Graneros, but neither has been observed in the Kiowa shale formation. Gypsiferous beds with a cone-in-cone structure are much more common in the Kiowa, although crystals of selenite are scattered plentifully through the shales of both formations.

Location and Occurrence of Samples Described

(El-43) Beds totaling 66.6 feet in thickness were exposed in pits excavated at location El-43. Of this total thickness, 21 feet fired to an ivory or to a cream color, 12 feet to buff, 8 feet to a dark buff, and 7 feet is red-firing. These beds, comprising a total thickness of 48 feet, are all excellent clays from the standpoint of ceramic use. Bed 19, here described, is, on the other hand, of little ceramic value, and is interesting only as an example of a typical Graneros shale.

Measured section of pits from which sample El-43-19 was taken, NW¼ NW¼ sec. 25, T. 15 S., R. 10 W., Ellsworth County.

Bed No.		Thickness. feet
	Graneros shale formation	
21.	Silt, clay, and fine sandstone, yellow and gray; contains concretionary limonite	1.9
20.	Sandstone, fine-grained, massive, brown and red	1.5
19.	**Clay shale, very plastic, yellowish gray with a band of concretionary limonite at top and bottom of bed**	**2.0**
18.	Siltstone, gray with some yellow; upper 1.5 feet massive, and contains root or stem molds; lower 3.8 feet thin bedded with horizontal bands of concretionary limonite	5.3
17.	Clay, plastic, gray with some yellow (dark buff-firing)	4.0
16.	Clay, smooth and fine-grained but hard, dark gray to black, with pronounced conchoidal fracture; contains leaf fossils (ivory-firing)	3.9
15.	Clay, slightly silty, light gray with a considerable amount of yellow stain on joints (cream-firing)	2.8
14.	Clay, silty, gray; contains some lignite (cream-firing)	3.2
13.	Sandstone, fine-grained, yellow with vertical jointing	0.9
12.	Clay, platy to thin-bedded, plastic (ivory-firing)	5.0

11.	Clay, plastic, gray to light gray; contains minute spherules of hematite and limonite (cream-firing)	2.8
10.	Siltstone, clayey, gray; contains a 7-inch band of gray clay	5.8
9.	Clay, fairly plastic, light gray (top 1.5 feet) to nearly black (bottom 4.6 feet); contains lignite (cream-firing)	6.1
8.	Clay, slightly silty, gray to dark gray with considerable amount of yellow stain (light buff-firing)	4.3
2-7.	Clay beds, mostly plastic, gray with a considerable amount of yellow and brown (dark buff- to red-firing)	14.6
1.	Clay, fairly plastic, gray with some brown mottling (buff-firing)	2.5
	Total thickness of section measured	66.6

The top of bed 21 is nearly at the brow of a hill which slopes steeply to the east and the west. A considerable tonnage of valuable clay (above bed 7) could be taken out by removing a little more than 10 feet of overburden (beds 18 to 21). A silty but light-firing face brick or fire brick could be made from a mixture of all of the beds, including the silt, from bed 8 to 17, inclusive.

(H-3) Bed 4 sampled at location H-3 includes material from both the Graneros shale and the Dakota formation. The silt, sampled from the Dakota formation, was added to the shale from the Graneros formation to reduce the excessive shrinkage typical of these extremely fine-grained shales.

Measured section of pits from which sample H-3-4 was taken, Cen. SW ¼ sec. 8, T. 23 S., R. 22 W., Hodgeman County.

Bed No.			Thickness, feet
	Graneros shale formation		
5.	Clay shale, gray with thin streaks of yellow sandstone; contains much gypsum		2.5
5c.	Sandstone, fine-grained, rusty brown, with some shale; contains much gypsum		0.6
5b.	Shale, silty, dark gray, contains much gypsum; a 1-inch band of white kaolin at bottom		0.8
5a.	Silt, gray, with paper-thin streaks of clay		0.8
	Total thickness of bed 5	4.7	
4b.	**Clay-shale, very fine-grained, plastic, dark gray; contains some pyrite**		3.8
	Dakota formation		
	Janssen clay member		
4a.	**Silt, friable, clayey, gray**		1.7
	Total thickness of bed 4	5.5	
3.	Siltstone, massive, resistant, buff		1.5

2. Siltstone, platy to thin-bedded, buff, gray, and yellow		2.2
1c. Clay, silty, gray with slight yellow stain		1.5
1b. Clay, fairly plastic, very light gray to nearly white; contains minute pellets of limonite		4.4
1a. Clay, plastic, gray with some yellow joint stain; contains root casts or molds partially filled with lignite		2.2
Total thickness of bed 1	8.1	
Total thickness of measured section		21.0

The shale portion of bed 4 (division b) is unusually free from impurities such as limonite, selenite, and silt for a Graneros shale. The occurrence of a pure shale of this character and in this same stratigraphic position—immediately above the Dakota-Graneros contact—is typical, however, particularly in areas where the contact is sharply defined. The thin streak of white kaolin, described as occurring at the bottom of division b of bed 5 in the measured section above, is of widespread occurrence although it is usually found immediately above the pure shale (division b, bed 4).

After firing, a thick efflorescence was noticed on the test bricks made from sample H-3-4. This, together with the presence of pyrite, indicates that soluble sulfates were plentiful in this part of the Graneros shale.

Bed 1 (sample H-3-1) is an unusually fine-grained plastic clay, probably of the ball clay class. The drying shrinkage is unusually high, and it is extremely dense firing, even at low temperatures. It fires to a cream color.

(RP-7) The beds sampled at location RP-7 were the only ones tested from the Graneros shale formation that gave any promise of being of practical ceramic value. The fact that these shales, although red-firing, behaved fairly well in drying and firing is probably due to the considerable amounts of silt and sand contained in the samples.

Location RP-6, across the road south of RP-7 and in the SE¼ SE¼ sec. 27, T. 3 S., R. 1 W., includes beds almost entirely in the Dakota formation, and formed a continuous series downward from the bottom of bed 1, location RP-7. Therefore, light-firing Dakota formation clays immediately underlie the beds described as occurring at location RP-7.

Beds 2 and 3 combined as one bed (bed A) produce a usable red-firing clay which, if combined with some of the silty beds oc-

Measured section of pits from which samples RP-7-2 and RP-7-3 were taken, NE¼ NW¼ sec. 34, T. 3 S., R. 1 W., Republic County.

Bed No.			Thickness, feet
Pleistocene (?)			
	Clay and silt, grayish brown, conglomeratic at bottom; contains fragments of brown sandstone		3.2
Graneros shale formation			
3b.	**Sandstone, fine-grained, silt and clay, occurring in thin beds, gray, yellow, and buff**		**5.0**
3a.	**Clay-shale, light gray with some yellow streaks; contains silt partings**		**4.3**
	Total thickness of bed 3	9.3	
2.	Clay-shale, gray to dark gray, with some silty partings and sulphur (?), rusty yellow limonitic sand streaks; a thin band of nearly black concretionary iron occurs at bottom of bed		12.5
Dakota formation			
Janssen clay member			
1.	Silt, clayey, gray with some yellow streaks		1.0
	Total thickness of measured section		26.0

curring immediately below, probably would produce a good dark buff-firing clay.

Mineralogic Properties

The shale beds of the Graneros formation are very similar to those of the Kiowa shale formation. Both are typical marine shales. The clay fraction in both cases is dominantly illite of the easily disintegrated, extremely plastic, fine-grained type which shrinks excessively on firing. The Graneros differs from the Kiowa shale formation in that light-colored bentonite beds occur in it. It is probable, therefore, that montmorillonite is an important, although quantitatively minor constituent of the Graneros shale. With this exception the discussion of the mineralogic properties of the Kiowa shale applies equally well to the Graneros, particularly in regard to the accessory minerals such as selenite, limonite, and pyrite.

The origin of a thin bed of white clay which usually occurs, if present at all, 4 to 5 feet above the Dakota-Kiowa contact, is difficult to explain. It is composed of either kaolinite or halloysite.

Chemical Properties

The chemical composition of the Graneros shales analyzed is similar to that of the Kiowa shales. This is to be expected because both shales are composed chiefly of the clay mineral illite and have the same physical properties.

The alumina to silica ratio is consistent with analyses of pure illite (Table 21), and the iron oxide content is comparable. The percentage of magnesium oxide for both is low. This may be due to errors in analytical procedure, or to unknown factors in the clay mineral content.

Constituents commonly present in Graneros shales but not included in the analyses (Table 24) are sulfur (present in the raw shale as iron sulfide), calcium sulfate, and traces of manganese and phosphorous.

Ceramic And Other Physical Properties

The ceramic properties of the Graneros shale are almost identical to those of the Kiowa shale. This similarity is not entirely due to the fact that both are composed dominantly of clay minerals of the illite group. Illite is the chief constituent of the red-firing shales of Pennsylvanian age, but these shales have drying and firing characteristics markedly different from those of the Kiowa and Graneros shale formations. In general, the Pennsylvanian shales slake slowly in water, and disintegrate into smaller particles with difficulty. Their drying shrinkage is comparatively low, and although their firing shrinkage is much greater than that of kaolinitic clays, it is sufficiently low to permit firing without

Table 24.—*Chemical Composition of Graneros shales described in this report*
(Analyses by Raymond Thompson and Russell Runnels)

	Constituents, percent								
Lab. No.	Silica (SiO_2)	Alumina (Al_2O_3)	Iron oxide (Fe_2O_3)	Titanium oxide (TiO_2)	Calcium oxide (CaO)	Magnesium oxide (MgO)	Potassium and sodium oxides (K_2O Na_2O)	Ignition loss	Total determined
El-43-19	55.63	25.84	3.77	1.01	0.85	1.27	2.76	8.36	**99.49**
H-3-4	59.47	19.90	4.30	1.08	0.99	1.97	1.03	10.62	**99.36**
RP-7-2	59.83	21.02	6.07	1.16	1.82	0.38	1.57	7.83	**100.12**
RP-7-3	72.80	11.97	4.00	2.26	0.48	0.43	4.05	4.36	**100.34**

cracking or bloating. The Graneros shale (and the Kiowa), on the other hand, slakes easily, will disintegrate into very small particles when agitated in water, and in comparison to Pennsylvanian shales, has a much higher drying shrinkage, and a somewhat higher shrinkage on firing. Furthermore, it is so extremely close-grained, and consequently tight-firing, that incomplete oxidation, bloating, and cracking commonly occur on firing the test bricks unless the clay is opened up with grog or some other inert material. Scumming is common on fired bricks made from either the Kiowa or Graneros shale due to the presence of soluble salts. Scumming is much less common on ware made from shales of Pennsylvanian age.

TABLE 25.—*Data on ceramic tests of Graneras shale samples*

Plastic and Dry Properties

Sample	Dry color	Water of plasticity, percent	Shrinkage water, percent	Pore water, percent	Volume shrinkage, percent	Calculated linear shrinkage, percent	Time required to slake 1" cube, minutes	Modulus Rupture lbs. per sq. in.
El-43-19	gray cream	38.1	23.8	14.3	45.6	13.3	15	209
H-3-4	dark gray	28.6	14.6	14.1	28.3	8.7	23	516
RP-7-2 (50% grog)	yellow gray	29.4	12.8	16.6	23.5	7.3		
RP-7-2	yellow gray	35.0	22.0	13.0	45.2	13.2	9	1364
RP-7-3	yellow gray	20.7	11.1	9.6	23.0	7.1	42	790

Fired Properties

Sample No.	Fired to cone	Fired color	Volume shrinkage, percent	Calculated linear shrinkage percent	Absorption, percent	Apparent porosity, percent	Apparent specific gravity	Bulk specific	Hardness	Best firing range (pyrometric cone)
El-43-19	07	dark orange	17.0	6.0						07 to
	02	red orange	22.5	10.7						4 (?)
	4	red	23.2	10.9						
H-3-4	04	red	12.1	3.9	9.8	19.3	2.46	1.98	H	05+
RP-7-2	06	red	8.3	2.9	11.3	21.6	2.42	1.90	S	05
50% grog	6	red	9.2	3.1	11.7	22.3	2.44	1.90	H	to 6+
RP-7-2	06	red	18.2	6.5						
RP-7-3	04	red	2.5	0.8	8.7	17.4	2.42	2.00	S	07 to
	5	red	5.6	1.9	7.7	16.0	2.48	2.08	S	above 5

Data on the fired properties of the Graneros shale (Table 25) samples are incomplete because the short bricks, upon which volume shrinkage and absorption were determined, cracked or bloated in firing. The cracking and bloating was much worse in the short than in the long bricks because small amounts of kerosene, used for dry volume determinations, remained in the bricks and interfered with complete oxidation during firing.

Samples El-43-19 and RP-7-2 are most nearly typical of pure Graneros shale, and have the highest percentage water of plasticity and drying and firing shrinkage. The percentage values of these properties are considerably lower for samples RP-7-3 and H-3-4 due to the effect of a considerable proportion of silt and sand mixed with clay. Similar results were obtained with sample RP-7-2 after the addition of 50 percent grog to the plastic clay. The grog was prepared by calcining some of sample RP-7-2 to cone 06, then crushing and screening the resulting grog to eliminate sizes smaller than 80-mesh and larger than 30-mesh.

It is evident that the only practical method of utilizing the Graneros shale is to mix with it 50 percent or more of inert ingredients such as grog, silt, or sand. This shale has such a high bonding strength and plasticity that probably as little as 15 percent added to a pure silt or ground flint (silica flour) would be sufficient to produce workable plasticity and a fairly high fired strength. Such mixtures tend to fire to a brown color. Small amounts of Graneros shale added to a white - or ivory-firing highly siliceous fire clay, however, greatly increase the plasticity, workability, and fired strength, and produce a buff color in the fired brick.

Both the Graneros and Kiowa shales have a tendency to bloat. This characteristic is detrimental to their use in standard structural clay products but there is a possibility of taking advantage of the tendency to bloat in the production of light-weight insulating and structural tiles or blocks. Some of our test bricks bloated to produce a fine-textured porous material having a specific gravity of 1.0 or lower.

These shales should also be suitable for the production of lightweight aggregates such as Haydite.

UTILIZATION OF CLAYS

Clay products have an important bearing on our daily lives. Articles for domestic use such as tableware, pottery, cooking and kitchen ware, and sanitary ware have nearly universal usage. Decreasing forest reserves with the consequent increase in the cost of lumber, together with a growing public demand for permanent and fireproof structures, has stimulated the growth of the clay products industries, and we may expect the demand in Kansas for brick and tile, particularly in the construction of farm buildings and the better class of city dwellings, to increase enormously in the future.

Clay, like water and fuel, is one of the substances essential to many modern industries. Wherever high temperatures must be attained, as in boiler fire-boxes, furnaces, and kilns, a refractory substance which will withstand these temperatures must be used. In most cases this refractory material is fire clay. From other types of clay are made the brick and tile used to house industry. Clay is also used in the manufacture of crucibles, filters, electrical insulators, chemical containers, and conduits, all of which are so common in industry that their value tends to be ignored.

The great variety of products made from clay is shown in the following outline. Most of these products can be made from Kansas clay.

Uses of Various Types of Clay

Heavy clay products (made from clay or shale of most types; usually made from medium to low grade and red burning, but also buff burning fire clay):

- Structural
    - Common brick
    - Face brick (may be glazed)
    - Paving brick
    - Hollow tile
        - Back-up and partition tile
        - Facing and/or load-bearing tile (may be glazed)
    - Quarry tile
    - Roofing tile (may be glazed)
    - Coping tile (salt glazed)
    - Terra Cotta
- Nonstructural
    - Drain tile
    - Sewer pipe (usually salt glazed)
    - Conduits (usually salt glazed)

- Stoneware (salt glazed, slip glazed, or Bristol glazed)
- Flower pots

Refractories (made from clay capable of withstanding high temperatures, usually buff burning):

Standard nine-inch brick Blocks and tiles Other special shapes	Includes light-weight insulating, as well as standard density shapes

Pottery (made from red-firing clay and shale and from white to buff-firing fire clay):

- All-clay
  - Stoneware
    - Domestic
    - Chemical
    - Electrical insulating
    - Art pottery
    - Kitchen and cooking ware
  - Earthenware
    - Art pottery
    - Kitchen and cooking ware
    - Flower pots
    - Garden pottery

Whiteware (made from mixtures of ball clay, kaolin, feldspar, flint, etc. Usually contains less than 50 percent ball clay):

- Vitreous products
  - Porcelain tableware
  - China tableware
  - Hotel and restaurant china
  - Sanitary ware
- Semivitreous products
  - Porcelain tableware
  - China tableware
  - Fine earthenware
  - Art ware
  - Majolica
- Whiteware—Miscellaneous
  - Floor tile
  - Wall tile
  - Electrical fixtures
  - Refractory porcelain (usually vitrified)
  - Chemical porcelain (vitrified)
  - Technical products

TYPES OF CLAY PRODUCTS

The qualities which determine the usefulness of a clay for a particular purpose are only partially related to the types by which clays are classified in this report. One type of clay may be suitable for use in manufacturing several kinds of products, or many types of clay may be suitable for making one kind of product. For example, a plastic fire clay may have properties which make it equally suitable for use in the manufacture of brick and structural tile, refractories, pottery (including earthenware, stoneware, and whiteware), and decorative tile.

HEAVY CLAY PRODUCTS

The heavy clay products include those which are usually manufactured on a large scale, and at a relatively low cost per ton. The clays or shales have only moderate value before processing, and seldom have sufficient value to be sold as raw, crude clay.

Almost any type of clay which can be formed by means of standard clay-working machinery and dried and fired to a sound product can be used in the manufacture of heavy clay products, although the choice of clay is limited somewhat by the color, size tolerance, fired porosity, and other qualities desired in the final product. Chiefly heavy clay products are manufactured from red-burning clay or shale, although buff or lighter-burning fire clays are used in the manufacture of face brick and tile, stoneware, terra cotta, and other products.

STRUCTURAL CLAY PRODUCTS

Structural clay products include wall-forming units such as common and facing brick, back-up and partition hollow tile, terra cotta and silo tile, and units having other constructional uses such as quarry and roofing tile. The ware may be glazed or unglazed, although commonly structural products are not glazed. The glaze may be produced either by "salting" the kilns, or by applying a mixture of chemicals by spraying or dipping the unfired ware.

Clays of the Dakota formation are suitable for the manufacture of all types of structural clay products. For this purpose the quality of the clays is superior to that used in most places. In general shales and surface clays are used in the manufacture of this type of product. The fired, or "burned" colors of shales and surface clays are usually limited to various shades of red unless artificially tinted by manganese or zinc. Generally these materials have a short firing range, and are difficult to vitrify. The Dakota formation clays of Kansas, on the contrary, fire to colors ranging from ivory to dark buff, as well as to the usual reds. They have a remarkably long firing range, and in most cases, a long vitrification range. The one disadvantage of the Dakota formation clays is one which inevitably accompanies the above advantages. Inasmuch as they are fire clays they require a relatively high temperature to attain maturity.

The Dakota formation clays found in Kansas are not all equally suitable for the manufacture of structural clay products. The more plastic clays tend to laminate on extrusion, have a high drying shrinkage, and tend to crack in drying. Except in extreme cases these defects may be remedied by adding grog or sand to the clay, or by dry pressing. These defects are particularly noticeable on some of the red-firing clays which in some cases contain a relatively high percentage of very fine-grained clay.

The highly siliceous clays, on the other hand, cause no trouble in extrusion despite their high silt content. They dry with a minimum of care, and have a sufficiently high green strength. Their maturing temperatures are often extremely high, and for this reason they are costly to use.

Some of the plastic fire clays and practically all of the siliceous fire clays are well suited to the manufacture of structural clay products. In general, they grind easily, require a minimum of pugging, and extrude with a minimum of power. Laminations may occur in the more plastic types, but they are not a serious problem. In some cases the more plastic types tend to crack on drying, but the less plastic ones cause no trouble. They may be fired rapidly and are not sensitive to a slightly reducing atmosphere.

Temperatures to which the clays must be fired or '"burned" vary greatly not only with the requirements of the product but with the individual deposit. For soft-fired porous products the maturing temperature in a few clays is as low as cone 05, and ranges from this to the maximum possible for economical production. Hard-fired semivitreous ware may be produced from some clays at temperatures as low as cone 4.

As a result of the tests conducted by the Geological Survey a brick and tile plant is now operating at Concordia (Cloud Ceramics).

The clay which is being used (location C-51) fires or burns to a good buff color at cone 9 (about 2,240° F.). The clay grinds easily in a dry pan as it comes from the pit, extrudes smoothly with a minimum of lamination, dries without special care, and causes no trouble with cracking or warping either in drying or firing. The drying and firing shrinkage is moderate. The successful production of brick from this clay proves conclusively that clays of the Dakota formation in Kansas are suitable for the manufacture of structural clay products.

The construction of another brick and tile plant at Great Bend (Great Bend Brick and Tile Company) is under way. This plant will also produce buff brick and tile from Dakota formation clay.

NONSTRUCTURAL PRODUCTS

Heavy clay products not used for structural purposes include drain tile, sewer pipe, conduits, stoneware, and flower pots. In general, the same types of clay or shale are used in these as in structural clay products. Stoneware, however, must be made from a fire clay which vitrifies at a relatively low temperature. If the product is to be salt glazed the clay must also be somewhat siliceous. The plastic and siliceous fire clays from the Dakota formation of Kansas are ideally suited to the production of stoneware.

Sewer pipe must also be made from clay which can be fired to near vitrification and which will take a salt glaze. Both siliceous fire clay and siliceous red-burning clay are used for sewer pipe.

Drain tile and flower pots are manufactured from open-burning, usually red-burning clay or shale. Material suitable for the manufacture of these products is available throughout most of Kansas.

Both red-firing and buff-firing clays are used in the manufacture of roofing tile. The requirements as to fired color, resistance to weathering, and forming properties are somewhat more stringent than those for such products as facing brick and hollow tile. Many of the Pennsylvanian shales as well as the Dakota clays of Kansas are suitable for roofing tile, however. The second largest roofing tile plant in the world is operating at Coffeyville, Kansas. It is using shale from the lower part of the Coffeyville formation. The Weston shale, formerly used at the same company's dismantled plant at Peru, is of equal quality.

Shale or clay used in the manufacture of paving brick or quarry tile must be capable of retaining its shape at vitrification and be resistant to abrasion and weather. During the heyday of paving brick a product of excellent quality was manufactured in Kansas from several Pennsylvanian shales.

REFRACTORIES

Although no statistics on the annual consumption of refractories in Kansas are available, it is obvious that an enormous tonnage is used when we realize that all public utilities and industrial power plants, oil refineries, lead and zinc smelters, foundries, and cement plants are large users of firebricks. The distribution of sales of refractories in the United States for 1935 was estimated as follows (Sullivan, 1938).

Industry	Percentage of Sales
Iron and steel	50
Public Utilities	20
Non-ferrous metals	6
Cement and lime	5
Glass	5
Oil refining	4
Ceramic miscellaneous	3
Miscellaneous	7

It is probable that the percentages used by public utilities and by the oil refining industry in Kansas are considerably higher than for the nation as a whole. From this it would seem that Kansas is a fairly good market for refractories.

A more detailed but by no means exhaustive list of the uses for fire-clay refractories is given below.

- Domestic uses
  - Furnace fireboxes
  - Fireplaces
  - Incinerators
- Public utilities
  - Boiler settings
  - Incinerators
- Industrial power and heating plants
  - Boiler settings
  - Flues
- Metallurgical processes
  - Aluminum melting furnaces
  - Annealing ovens
  - Bessemer converters
  - Brass melting furnaces
  - Copper furnaces

  - Copper converters
  - Crucibles
  - Heat treating furnaces
  - Iron blast furnaces
  - Lead furnaces
  - Nickel furnaces
  - Open hearth furnaces
  - Zinc retorts and condensers
- Ceramic processes
  - Clay industry
    - Brick and tile kilns
    - Pottery kilns
    - Kiln furniture
  - Cement and lime industries
    - Rotary kilns
    - Vertical kilns
  - Enameling industry
    - Enameling furnaces and kilns
    - Frit furnaces
  - Glass industry
    - Glass tanks
    - Glass pots
    - Lehrs
  - Rock wool and slag wool industries
    - Cupolas
    - Reverberatory furnaces
  - Petroleum industry
    - Oil gas sets
    - Refinery stills
    - Boiler settings

Kansas fire clays so far tested have been classed as intermediate heat duty or low heat duty refractories (A. S. T. M.—Designation: C-27-41). Intermediate heat duty clays must have a pyrometric cone equivalent of not less than cone 29 (approximately 2,984° F.), or deform not more than 3 percent at 2,460° F. Almost all the Kansas clays tested have a pyrometric cone equivalent ranging between cone 26 and cone 30 (2,903° to 3,002° F.). Some of the clays stand up better under use and under load at high temperatures than their pyrometric cone equivalent indicates. It is possible that when more thorough tests have been made some of the clays will be classed as high heat duty refractories.

Actually the limitations of the Kansas clays for use as refractories cannot be determined with accuracy from the pyrometric cone equivalent. The test kiln in the Geological Survey laboratory used small bricks made from siliceous Kansas fire clay (TC-2-10) as kiln furniture. These bricks were placed on the floor of the kiln in the zone of highest temperature, and supported the entire load of ware in the kiln. These bricks showed no indications of deformation or other deterioration, although used for four years at temperatures ranging up to 2,550° F. Other clays having a pyrometric cone equivalent of cone 29 show no ill effects when used at a temperature of 2,750° F. The A. S. T. M. standards make allowances for such differences in fire clays. Clays which withstand rigorous re-heat, or re-heat under load tests, may have a lower P. C. E. than is indicated for the particular class. We believe, therefore, that many of the Kansas fire clays which are classed as intermediate heat duty according to their P. C. E. are actually high heat duty fire clays.

Although the pyrometric cone equivalent of the Kansas fire clays does not vary with the silica content, other significant qualities do vary with the silica. The clays relatively high in alumina and low in silica stand up well under heat shock, and are relatively tough. The more siliceous clays, on the other hand, are volumetrically more stable and deform less under load at higher temperatures than the less siliceous clays.

Experiments conducted by the Geological Survey indicate that the plastic fire clays and ball clays are readily susceptible to beneficiation by means of settling or centrifugation in water suspensions. The alumina content of one clay (C-27-13a) was increased from about 26 percent to about 36 percent by this treatment. The P. C. E. was also increased from cone 29 to above cone 31, thus placing the beneficiated clay in the high heat duty class. About 50 percent of the clay is recovered from this process. The residue is a siliceous clay suitable for use in the manufacture of facing brick or intermediate heat duty refractories.

We can state with assurance that Kansas fire clays are suitable for any installation where they will be subjected to moderate temperatures. In general, this means temperatures under 2,500° F. Specifically such installations include zones of low and moderate temperatures in boiler settings, stills, and kilns in which more refractory clays are used in the high temperature zones, and other installations or uses such as incinerators, kiln furniture, saggers, flue linings, and back-up brick in which the Kansas clays can be

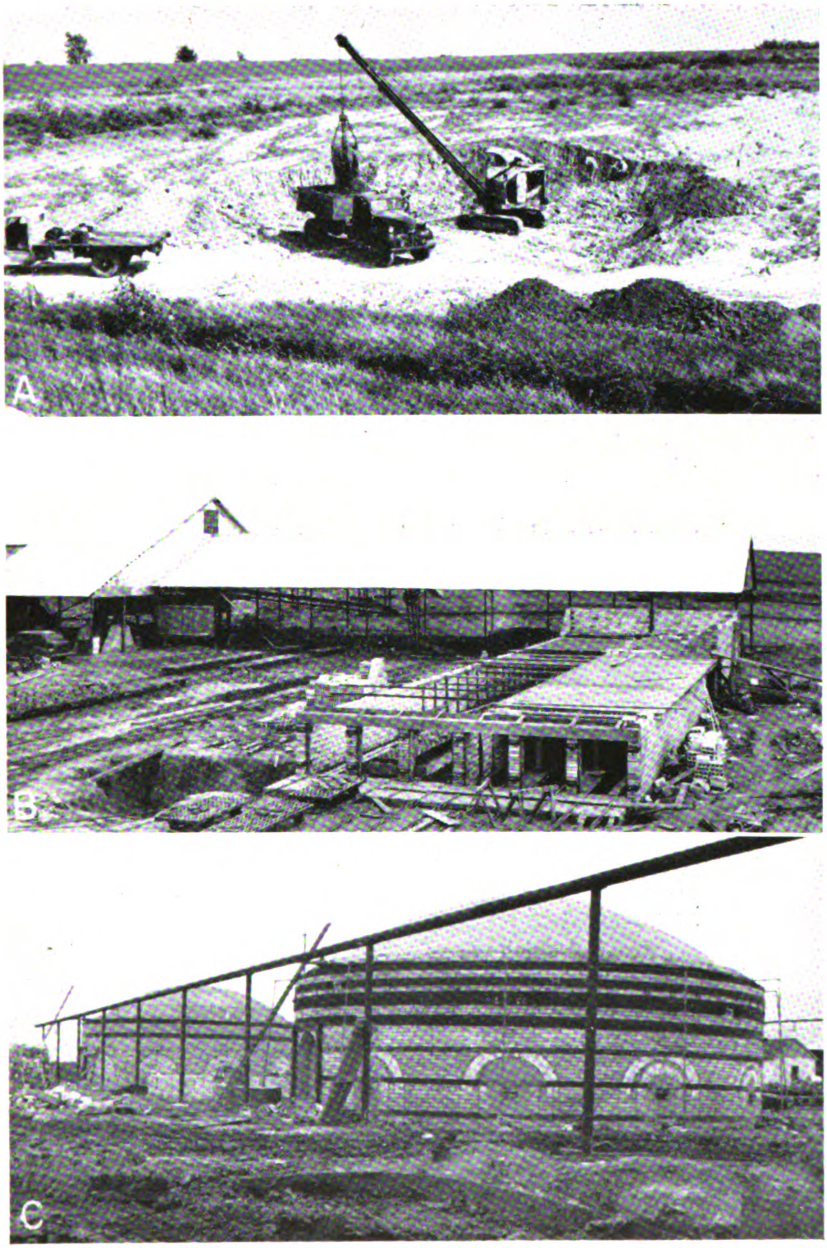

PLATE 7.—Views of the new brick and tile plant at Concordia (Cloud Ceramics). At the time the photographs were taken the production of brick had started, although the plant was still under construction. This plant was constructed as a result of the testing of Dakota formation clays by the Geological Survey. *A*, View of clay pit. *B*, Factory building with incompleted drier in foreground. *C*, Periodic kilns now being used for burning brick.

used throughout. Some of the more siliceous clays are ideally suited for use in ladle brick and zinc retorts and condensers.

The most extensive application of Kansas clay as a refractory has been at the brick and tile plant at Concordia (Cloud Ceramics) where brick made from the clay in its own pit has been used in part in the construction of their down-draft beehive kilns. The same clay was used as mortar in laying up almost all the fire bricks. These kilns are fired at temperatures ranging up to 2,300° F. The face bricks which are being burned in these kilns are made from the same clay used in the construction of the kilns (Pl. 7).

Many thousands of fire bricks are shipped into Kansas each year. In most of the installations in which these firebricks are used, Kansas fire clays would serve equally well. The manufacture of refractories, however, is an industry which requires technical knowledge, careful controls, and experience. The sale of refractories also depends to a large degree upon the established and favorable reputation of the manufacturer. These facts must be taken into consideration by a new refractories industry, but they are not necessarily unsurmountable difficulties.

POTTERY

The term "pottery" as understood by the ceramic industry includes a great variety of wares ranging in quality from flowerpots to the highest grade of fine china, or the best laboratory porcelain, and ranging in size from the minute laboratory ware used in micro-analysis to huge stoneware containers several feet in height. It also includes such strangely associated wares as tableware, chemical porcelain, sanitary ware, and art pottery. The materials from which pottery is made are equally varied. These materials, or pottery "body," range from the crudest type of red-firing clay to admixtures of extremely pure ball clay, kaolin, silica flour, feldspar, talc, and many other ingredients. A list of the various types of pottery is given in the introductory statement to the section on utilization of clays.

All-clay pottery.—Pottery which is made entirely from clay may, for convenience, be divided into two classes: (1) stoneware, which is nearly or completely vitrified, and therefore has very little porosity, and (2) earthenware, which is soft fired, and is highly absorbant. This classification is an oversimplification because in fact there is a complete gradation from highly vitrified stoneware to extremely porous earthenware.

The most commonly known type of stoneware is that found in ordinary crocks, jugs, and jars sold in hardware stores for domestic use. This type of stoneware is glazed in a cheap white Bristol type of glaze, or a brown slip glaze such as Albany slip. Less commonly a salt glaze is used. Art ware, kitchen ware, and tableware made with an all-clay body and vitrified are classed as stoneware. More expensive glazes with a finer finish are used on this type of ware. The better grades of such stoneware are nearly identical in appearance and quality to whiteware.

Chemical stoneware is somewhat similar to the ordinary crock and jug variety, but is made with much greater care, and is of a much higher quality. Much of chemical stoneware is salt glazed. The bulk of chemical stoneware consists of containers of various shapes and capacities, although pipes, conduits, still worms, valves, and other fittings are also made from stoneware. Stoneware is probably the most highly chemical-resisting material generally available for such uses.

The Kansas plastic and siliceous fire clays are especially suited for use in the manufacture of stoneware because of their long vitrification and firing range, and because they hold their shape well at vitrification temperatures. All types of glazes have been used on these clays, although some care must be used in the selection of clays, particularly in the higher temperature range, or shivering of the body results.

Ordinarily stoneware is made from a fire clay which vitrifies at a low temperature. The fired color is usually grayish white or ivory. Stoneware may, however, be pure white, or any color ranging from white to dark brown. If the ware is composed entirely of clay and is nearly vitrified it is stoneware.

Earthenware is in many cases made from the same clays that are used in making stoneware. In the case of earthenware the ware is fired to a much lower temperature, and has a relatively high porosity. If it is necessary for the ware to be impervious to water dependence is placed upon the glaze.

Almost any clay which is suitable for the manufacture of brick or tile can be used for earthenware. Red earthenware suitably glazed is in many cases superior, from the standpoint of resistance to impact and thermal shock, to lighter colored ware.

The greater percentage of earthenware manufactured consists of flower pots and cooking and kitchen ware. The flower pots are of course unglazed. Inexpensive but serviceable glazes are used on the cooking and kitchen ware. Red-firing Pennsylvanian shales are well suited to the manufacture of both the high porosity flower pots and the less porous glazed ware. Both red and ivory or buff ware can be manufactured from the clays of the Dakota formation.

Most art ware has an earthenware body covered with a relatively thick colored glaze, although in some cases clear or transparent glazes are used. Dakota clays are particularly well suited to the manufacture of this type of ware. The casting, throwing, or jiggering properties of the clays are excellent. These properties, in addition to the ease of drying and the relatively low temperature to which some of the less siliceous clays can be fired, contribute to the usefulness of the Dakota clays in this field. Several schools and small art potteries in Kansas are using Dakota clays and find them very satisfactory.

Whiteware pottery.—Although almost all whiteware is in fact white in color, or at least a light ivory, the name primarily connotes a type of body to the ceramic industry. Whiteware bodies are mixtures commonly consisting of ball clay, kaolin, flint (powdered silica), and microcline feldspar. Many other minerals are used, particularly of the feldspathic type. The most common are talc, nepheline syenite, soda feldspar, Cornwall stone, and spodumene. Whiting is also a commonly used ingredient, and flint comprises a considerable proportion of the mixture. In some cases a frit (a powdered low-fusion glass) is used to lower the maturing temperatures.

Kansas ball clays are suitable for use in the manufacture of whiteware. The bulk of the Kansas ball clays produce an ivory ware, although clay from some of the deposits will produce a white. The white-firing clays are much less common than the ivory-firing, but the actual tonnage available is quite large. The Kansas clays are similar to the Kentucky and Tennessee varieties, but on the average they contain less carbonaceous material and require less electrolyte for deflocculation. Despite the fact that the iron oxide content of Kansas clays is comparable to that of the Kentucky and Tennessee clays, the Kansas clays tend to fire to a somewhat darker color.

The properties of Kansas ball clays and the various types of fire clays are well suited to the various processes used in the manufacture of pottery. The clay is easily pulverized and slakes readily when mixed with water either as a plastic mass or in slip. Many of the clays do not require an electrolyte to deflocculate the slip. The clays work well either in slip casting, jiggering, throwing, or hand molding. They dry with a minimum of difficulty if properly proportioned. Due to a long firing and vitrification range, temperatures do not have to be controlled very closely. Most of the clays can also be fired on a remarkably fast schedule without cracking or bloating.

The ball clays have a high tensile strength and excellent bonding properties so that relatively small amounts of clay will produce a workable body. We have slip cast with a body containing as little as 25 percent clay with 75 percent volcanic ash. The latter material has no plasticity or bonding qualities.

A great variety of whitewares are manufactured. Tableware accounts for at least one-fourth of the total value of whitewares produced. In 1943 the American output of semivitreous dinner ware totaled 42 million dollars as compared with a total output of 179 million dollars for the entire whiteware industry. Ceramic electrical insulating materials comprise another 44 million dollars (Newcomb, 1947). According to Chute (1939) sanitary ware accounts for 68 million dollars of the total whiteware production. Therefore, these three types of products comprise approximately 85 percent of the total whiteware production.

Whitewares are in general classified according to the degree of vitrification of the ware. Vitreous whiteware has an absorption well under 1 percent. Semivitreous products have absorptions ranging from 0.3 percent to more than 15 percent. The following classification of dinner-ware bodies (Newcomb, 1947, p. 223) clarifies the relationship of ware to their physical properties.

The differences in the different types of whiteware are due largely to differences in temperature of firing body and glaze, and in thickness of ware. There are of course important differences in the ingredients of the body, particularly in the proportions, but the types of ingredients remain essentially the same.

Many types of glazes have been used with success on pottery and other ware made from Kansas ball clays and fire clays. These include low temperature (cone 07 to 04) art glazes, whiteware

	Name	Absorption, percent	Mechanical Shock Resistance	Translucency
(1)	Majolica	above 15	very low	none
(2)	Fine earthenware	10-15	low	none
(3)	Semivitreous china	4-10	med. to high	little or none
(4)	Semivitreous porcelain	0.3-4	high	low
(5)	Bone china	0.3-2	medium	high
(6)	American hotel china	under 0.3	very high	medium
(7)	American household china	under 0.1	very high	high
(8)	Belleek china	none	med. to high	high
(9)	Porcelain	none	med. to high	high

glazes, Bristol and other stoneware glazes, porcelain glazes, and salt glazing. These glazes ranged in composition from low-temperature fritted alkaline, to high temperature fritted and raw glazes. The high temperature raw glazes varied from the simple kaolin-flint-feldspar variety to clay slip glazes of the Albany slip type. We have been quite successful in the use of volcanic ash both as a body and glaze ingredient in conjunction with making pottery from Kansas clays. The volcanic ash darkens the color of both body and glaze, but otherwise has properties very similar to nepheline syenite or soda-feldspar.

So far, Kansas clays chiefly have been used for pottery making in schools and by small-scale potteries. The chief obstacle to their use on a large scale has been the lack of a producer or producers of the raw clay. Most pottery manufacturers are not equipped to mine clay, and do not wish to get into the business. Many manufacturers preferred to buy their clay pulverized and ready for use. A producer of raw clay must also be able to supply clay which is uniform in quality from shipment to shipment.

Pottery clay is being mined at two places in the State, but only enough to supply the demands of schools and craftsman is produced.

MISCELLANEOUS WHITEWARES

The same types of bodies used in the manufacture of pottery whiteware are also used in a number of classes of ware which cannot be classed as pottery. These wares include floor tile, wall tile, electrical fixtures, refractory porcelain, chemical porcelain, and several other technical products. Most of these products command a high price per ton, and are manufactured with a great deal of care. For some products in this class the Kansas ball clays and siliceous fire clays (technically a mixture of ball clay and silica flour) are not sufficiently pure. For most of them, however, the Kansas clays are entirely suitable. Among the uses to which Kansas clays are adapted wall tile probably should head the list. It is believed, however, that electrical insulators for high tension lines and similar uses can be made from the Kansas clays. The Kansas clays are also suitable for use in the manufacture of encaustic floor tile.

CERAMIC SLAG AND LIGHT-WEIGHT AGGREGATE

For the past 18 months the ceramics laboratory of the Industrial Minerals Division of the State Geological Survey has been experimenting with the production of vitrified or sintered clay and silt for use as concrete aggregate and railroad ballast. The material is fired or "burned" to a temperature higher than is suitable for the production of ordinary ceramic ware. The best product is usually produced at the temperature at which the clay softens and the individual pieces stick together. For a dense product such as is required for the usual concrete aggregate or for railroad ballast the material should be easy to oxidize in firing, and fired slowly enough to complete oxidation. Most clays will bloat and produce a light-weight aggregate if fired rapidly. This is particularly true if the clay is nonsiliceous and contains carbonaceous material or sulfur compounds. The Kiowa and Graneros shales are especially suitable for the production of light-weight aggregates. As a matter of fact, it is difficult to produce a dense product from these shales. The clays of the Dakota formation, on the other hand, can be fired into a durable dense aggregate or ballast with a minimum of care. The one objection to the Dakota clays is that a relatively high temperature is required for maturity. If red-firing clays relatively free from silt are used the maturing temperatures are not too high for economical production.

Either the dense or the light-weight aggregate can be produced in a periodic or a tunnel type of kiln, but we recommend the use of a rotary kiln. Experiments conducted in a batch type rotary kiln indicate that a wide variety of clays can be processed by this method. Unless the clay is entirely uniform it is desirable to grind the clay in a dry pan or pulverizer before firing it in order to produce a uniform product. The clay should be slightly damp as it is fed into the kiln to reduce the loss by dusting. As the temperature of incipient fusion is reached in the kiln the clay lumps and particles begin to "gather" and roll into a cylinder in the kiln. We have found that the temperature of the material must be carried to a point from 50° to 80° F. above the point at which the cylinder starts to form for best results.

Kansas loess deposits of Pleistocene age have proven especially suitable for the dense type of ceramic slag. In many cases clays of Dakota age are covered with Pleistocene clay or silt ranging in thickness from a few inches to 50 feet. This suggests the possibility of combining the production of ceramic slag with other types of clay products from the Dakota formation. The loess, which otherwise would be useless overburden, profitably could be used for the production of ceramic slag.

A separate report on the experimental production of ceramic slag will be published next year.

SUMMARY

Clays of the Dakota formation are not only available in large tonnages, but they are also available in great variety, ranging from nearly white-firing ball clays to dark red-firing clays. Maturing temperatures range from cone 06 to cone 18 or higher. Firing range and vitrification range extend over several cones. Therefore it is possible to find a clay suitable for almost any type of clay product.

The actual limitations on the use of this abundant supply of clay are those of selling, marketing, and transportation, rather than technical limitations in the ceramic field.

PURIFICATION AND BENEFICIATION

INCREASING THE ALUMINA CONTENT

For use in the manufacture of refractories, the Kansas fire clays are limited to intermediate and low heat duty applications by the pyrometric cone equivalent, which in most cases does not exceed cone 30.

Experiments conducted in the ceramics laboratory of the State Geological Survey for the purpose of concentrating the alumina-containing portion of the Kansas fire clays indicate that both the alumina content and the fusion point of the clays can be increased by differential settling in water suspensions, or by centrifugation.

The alumina-containing portion of the clays is chiefly kaolinite which contains about 39.5 percent alumina, 46.5 percent silica, and 14 percent chemically combined water. The Kansas clays rarely contain more than 75 percent kaolinite. The remaining 25 percent is very finely divided quartz, most of which will pass a 200-mesh screen. Clays available in large tonnages commonly contain about 65 percent kaolinite and 35 percent free silica or quartz.

Owing to the fact that the kaolinite particles are very small in size and capable of being suspended in water, and that the free silica or quartz will settle out in water, it is possible to separate most of the kaolinite from the free silica. By repeated cycles of settling in suspensions of 75 to 85 percent water it was possible to obtain clay having an alumina content of 39 percent.

One of the clay samples which was concentrated by sedimentation is C-12-13a (analysis in Table 10). The alumina content of the raw clay is about 27 percent. Six tests were run on this clay in suspensions containing 80 percent water and 20 percent clay by weight. The pH of the suspensions were varied from 7.0 to 10.6 by the addition of increasing amounts of ammonia hydroxide, as deflocculent. The clay suspension had a pH of 7.0 without the addition of any deflocculent. No significant difference due to increase of pH was noted in the results.

In the first cycle of sedimentation the clay was allowed to settle for 24 hours in graduated glass cylinders. At the end of this period the cylinder, by volume, contained 90 percent clay in suspension and 10 percent semisolid residue in the bottom. The clay suspension contained approximately 51 percent of the weight of the original solid, and the residue 49 percent. The clay suspensions contained 34 to 35 percent alumina and 48 to 49 percent silica. The residue contained 17 to 19 percent alumina and 70 to 73 percent silica.

Both the clay suspension and the residue were again diluted to 80 percent water by weight and allowed to settle for 24 hours. A small amount of free silica with clay adhering settled out of the previous clay concentrate. The maximum alumina content obtained from the second cycle of sedimentation was close to 39 percent. The residue contained about 20 percent alumina and 70 percent silica. The second cycle on the first residue yielded by weight about 10 percent clay concentrate and 90 percent siliceous residue. The clay concentrate contained 35 to 36 percent alumina and 48 to 49 percent silica. The siliceous residue contained about 18 percent alumina and 75 percent silica.

It is doubtful if the second cycle of sedimentation yields enough concentrate to pay for the process. The first cycle yields at least 50 percent concentrate, with a residue which is suitable for use as a silica refractory or for facing brick.

The raw concentrate contains about 36 percent alumina. The calcined concentrate, due to the removal of chemically combined water, has an alumina content of about 40 percent, an increase of about 9 percent alumina over the untreated calcined sample. These experiments are discussed briefly under the mineralogic properties of ball clays. This is sufficient to increase the pyrometric cone equivalent (P.C.E.) from cone 29 to cone 32, and the classification from an intermediate heat duty fire clay to a high heat duty fire clay.

The same results were obtained in a centrifuge in five minutes as were obtained by gravity separation in 24 hours. It is probable that the most practical method of concentrating the clay would be by the use of a continuous centrifuge followed by continuous filtration to remove the bulk of the water. We have estimated the cost of the sedimentation process, including mining, to be not more than $1.00 per ton of concentrate.

DECREASING THE IRON CONTENT OF CLAY

Ball clays or plastic fire clays which are to be used in whiteware or light-colored earthenware should have as low an iron content as possible. Although the percentage of iron found in some of the Kansas clays is comparable to that found in Kentucky and Tennessee ball clays, much larger tonnages are available if some method of decreasing the iron oxide content were used.

Not all the clays sampled by us were selected in the process of sampling. Analyses included in this report are therefore based on unselected samplings. We have found, however, that sampling with a reasonable amount of care in eliminating iron oxide-containing streaks and joint fillings substantially reduces the total content of iron oxide. Inasmuch as ball clays intended for use in pottery making commonly are selectively mined, no unusual cost is added.

In many cases an appreciable portion of the iron oxide contained in a clay sample is present as small concretions of siderite or limonite, or as the cementing material between small aggregations of sand grains. Both of these iron-bearing materials are largely removed by the usual screening of clay slip through a 100-mesh to 200-mesh screen. The finer the screen, the greater amount of iron there is removed. This process does not entail extra cost. The only precaution to be observed is that the clay should not be subjected to fine grinding before blunging. Fine grinding will break up the iron-containing nodules so that they will pass a fine screen. Most of the clays blunge easily without excessive grinding.

Magnetic separation used on the slip will also remove much of the iron-bearing portion providing a strong magnetic field is used.

ECONOMIC FACTORS AFFECTING UTILIZATION

EXTENT OF CLAY DEPOSITS

In terms of tonnage available the red-firing to dark buff-firing clays comprise about two-thirds of all the clays available in the Dakota formation in Kansas. The buff or lighter firing clays comprise the remaining one-third. Of these the plastic and siliceous fire clays are available in much larger tonnages than the other types. The ball clays and highly siliceous fire clays, although much less extensive, are available in such large quantities that supply exceeds any probable future commercial demands. Kaolin deposits so far discovered are sufficient only for restricted use.

The shales of the Kiowa and Graneros shale formations are suitable for very few types of products, although the supply is comparatively large.

It is extremely difficult, if not impossible, to estimate the total available tonnage of the various types of clay. Furthermore, an estimate of the total available tonnage would be of little practical value. For practical purposes each deposit, or closely related groups of deposits, will be explored and considered as economically exploitable units.

Data obtained from drill holes put down in Cloud, Ottawa, and Ellsworth Counties by private concerns and by the United States Bureau of Mines have revealed that little about the actual tonnage of clay available in any one deposit can be learned from surface outcrops. For example, the clay deposit now being used by Cloud Ceramics at Concordia was very carefully explored by means of drill holes. From the data thus obtained the total tonnage available was estimated at two million tons. A previous estimate based on measurements of outcrops placed the total reserve at a quarter of a million tons, or one-eighth of the total tonnage actually available. In other cases estimates based on measurements of outcrops were correspondingly high. In 1944 the Bureau of Mines explored three clay deposits by augering. From surface indications it was inferred that the three deposits contained about equal tonnages of usable clay. The tonnages estimated after drilling follow (Anonymous, 1944, pp. 4-5).

Unit deposits including clay locations identified by index numbers (see Table 26)		Estimated material in tons
A	C-27, O-40, and O-6	3,142,000
B	El-91 and El-92	192,000
C	El-14, El-69, El-72, and El-90	2,238,000

The above figures are probably fairly indicative of the range in size of deposits of high-quality clay. They also demonstrate very clearly that estimations of tonnage from surface indications are very misleading.

In summary, clay of any of the varieties found in the Dakota formation, with the exception of kaolin, occurs in deposits of sufficient size for any type of commercial exploitation throughout most of the outcrop area in Kansas.

SHAPES AND FORMS OF THE CLAY DEPOSITS

Although related beds of clay and sandstone of the Dakota formation are considered to be stratigraphically and lithologically continuous, from the point of view of economic utilization of the clay beds they are not continuous, but must be considered as individual or closely related individual deposits. So far as can be determined, some beds of clay are fairly uniform in thickness and in ceramic characteristics over an extent of several square miles. For all practical purposes, however, the individual user of clay will not be concerned with reserves exceeding one million tons. A million tons is sufficient to supply a moderate-sized brick and tile plant for 40 years, or a large one for 20 years.

The individual clay deposits so far explored have been found to occur in elongated lenticular bodies, or in elongated, relatively narrow bodies resembling channel fillings. In fact, some probably are channel filling, others between-channel deposits, and others the mud filling of lagoons occurring behind barrier beaches. The long axes of these bodies usually lie in a north-northeast-south-southwest, or a north-northwest-south-southeast direction. One such elongated clay body, portions of which were sampled at locations C-27, O-40, O-6, and O-38, averages about one-eighth of a mile in width, and is at least 3 miles long. The north part of this deposit extends from the NW¼ NW¼ sec 32, T. 8 S., R. 2 W., to the NW¼ NE¼ sec. 8, T. 9 S., R. 2 W., roughly in a NNW-SSE direction for a distance slightly exceeding 2 miles. The same deposit was detected again in the SW cor. sec. 8, T. 9 S., R. 2 W., and in the SE cor. sec. 7, T. 9 S., R. 2 W., indicating that the clay body turns rather sharply from its NNW-SSE direction to the NE-SW. The clay body consists of a siliceous fire clay, underlying a pure ball clay. The total thickness is as much as 20 feet in some places.

The clay body which comprises the reserve for Cloud Ceramics, Concordia, is largely confined to an area of about 20 acres. The body is in the shape of an elongate lens, with its long axis lying in a NNE-SSW direction. The clay has a maximum thickness of more than 100 feet. The point of maximum thickness lies on the central long axis, but southwest of its center.

In general the beds of siliceous or highly siliceous fire clay are thicker than those of ball clay or plastic fire clay. Highly siliceous fire clay is known to occur in beds as much as 40 feet thick, and 20-foot beds are not uncommon. Ball clay and pure plastic fire clay, on the other hand, occur in beds having perhaps a maximum thickness of 20 feet, but are only rarely more than 10 feet in thickness. Red-firing or dark buff-firing clay is known to occur in beds as thick as 90 feet, and in general it occurs in much thicker beds than those of the lighter-firing clays.

MINING

Clay is seldom mined other than by open pit methods, unless some other more valuable material, such as coal, is being taken out with the clay. It is assumed that clays of the Dakota formation, or contiguous beds, will be mined by the open pit method.

Questions frequently asked are: "What is the thickness of overburden which must be removed from the clay beds?" and "How far below the surface is this clay?" In places relatively large amounts of clay can be removed without stripping off any overburden, but in general the overburden varies from a few inches to a depth beyond which economical recovery of the underlying clay beds would not be feasible. Any person interested in the commercial mining of the Dakota formation clays should determine the thickness of overburden and thickness of usable clay beds by carefully and closely-placed drill holes before making an investment.

Easily excavated materials such as Pleistocene silts and clays and loosely consolidated Dakota sandstone have been removed and hauled to a disposal pile for 15 cents per ton with a 5-yard tractor scraper. The cost is estimated to range from 10 to 25 cents per ton, with 15 cents as a good average for the types of overburden encountered in central Kansas. The cost of removing usable clay will be somewhat higher. The thickness of overburden which may be removed economically in relation to the thickness of usable clay depends, of course, upon the value of the clay, or the clay product which is manufactured from the clay. Whitlatch (1940) estimates that a maximum of 10 feet of overburden may be removed for each foot of ball clay, but that most operators prefer to keep within a five to one ratio of overburden to clay. These ball clays are sold for use in quality products and represent the upper limits of value on raw clay. The manufacturer of common brick, on the other hand, cannot afford to remove an overburden greater in thickness than his clay or shale bed. Judging from current operations brick plant operators do not mine clays or shales which have an overburden greater than one-third the thickness of the usable clay bed.

The Dakota formation clays are usually hard and extremely tough, and have few joints or bedding planes. For these reasons it is nearly impossible to excavate the clays with a small power shovel without first "shooting" the clay. The clay usually contains just enough moisture to give it maximum toughness and hardness. On the whole this is an advantage in that the clay is sufficiently dry to be crushed immediately after taking in from the pit. Once subjected to a thorough wetting either by heavy rains or seepage the clay slakes rapidly and absorbs a sufficient quantity of water to become slick and difficult to handle. Usually it dries rapidly after rains, because water penetrates slowly, but once soaked by seepage or surface drainage the clay will remain wet for a long time.

As is to be expected in clays of the Dakota formation types, the beds are not entirely uniform in composition or thickness. For this reason clay which is to be used or sold for special uses, such as ball clay for pottery making, will have to be mined with a certain amount of care to avoid streaks containing excessive iron, silt, or other undesirable constituents.

TRANSPORTATION

The outcrop area of the Dakota formation is fairly well covered with a network of railroads and all-weather roads. Railroads in the area include the Burlington, Frisco, Missouri Pacific, Rock Island, Santa Fe, and Union Pacific. The area is crossed by highways U. S. 36, U. S. 24, U. S. 40, U. S. 50, U. S. 81, U. S. 283, and a number of all-weather State highways.

In many cases the railroads miss the more important clay areas by several miles. This is due largely to the fact that railroads follow streams, or areas of low relief, whereas the clay deposits are better exposed in areas of maximum relief. Important exceptions are along the Union Pacific, Missouri Pacific, and Frisco lines through Ellsworth County, the Union Pacific and Sante Fe branch lines through Ottawa and Cloud Counties, and the Burlington in Washington County.

FUEL

Any clay products manufacturing plants which will be constructed in the area will probably use natural gas as fuel. Oil is a practical and economical fuel for use in firing kilns, and in places where natural gas is not available, or where rates are too high, it will be used. Coal is used for fuel to some extent in Kansas where the plants are fairly close to coal mines. In such cases the lower cost of coal as a fuel offsets the inconvenience experienced in its use.

The parallel natural gas pipe lines of the Natural Gas Pipeline Company of America and the Northern Natural Gas Company extend across the entire outcrop area of the Dakota formation. The pipeline of the Kansas Power and Light Company serves portions of Clay, Cloud, Republic, and Washington Counties.

MARKETS

It is difficult to estimate the extent of markets for the various types of products which can be manufactured in the area in which the clays of the Dakota formation crop out. For example, estimates of the radius of sales which were considered practical for Cloud Ceramics (Concordia) have proven entirely erroneous in practice. Prior to operation of the plant it was estimated that the maximum practical radius from Concordia for sale of buff face brick was 200 miles. Actually large quantities of brick are being sold at least 500 miles from the plant, and sales within a radius of 50 miles are negligible. Another example of misleading character of market surveys may be discovered by comparing Kreuger's estimates with actual experience. To quote from Kreuger (1940, p. 33): "If it is assumed that a new buff [brick] plant could obtain sales of 2,000,000 brick per year, which would be unlikely, it would mean that a plant with a 14,000 brick per day capacity could operate six months of the year." Kreuger based his estimates on total sale of buff face bricks in Kansas for 1939, which totaled only 1,993,350 brick. Cloud Ceramics is making and selling at least 750,000 bricks per month, and expects to increase its capacity. They plan to operate 12 months of the year, and will therefore produce at least 9,000,000 brick per year. The discrepancy between estimate and fact is not entirely due to the increase of building due to the war. Chiefly it is because it was impossible to predict the fact that the Kansas product could compete with locally produced buff brick on a distant market.

The most obvious markets for the Dakota clays are in the production of buff face brick and tile, pottery, and the sale of raw clays such as the ball clay and plastic fire clay. Numerous inquiries received by the Geological Survey indicate that there is also a demand for glazed structural tile, glazed wall tile, encaustic floor tile, and electrical insulators. All of these products can be made from Kansas clays.

The large tonnage of fire-clay refractories consumed in Kansas indicates a potential market for firebrick made from the Dakota fire clays, but as was stated in an earlier section, the reputation of established producers and buyer habits are rather difficult obstacles for the newcomer to overcome in the production of refractories in Kansas. An established brick plant in the fire-clay area could test out markets on a small scale without much additional investment or risk.

During the war and up to the present pottery has been a very easily sold commodity. This is especially true of art pottery. Several small producers are operating successfully in Kansas. The total output of these producers, however, is very small and the sales do little to indicate what could be expected in the way of markets for large-scale production. The general opinion is, however, that there is, and will continue to be, fairly good market for both tableware and art pottery because the production of such wares is very small in this general area. Shipping costs on ware from Ohio, for example, add considerably to local retail prices. It is probable that this difference in shipping costs would enable Kansas producers to compete with more distant manufacturers.

The Geological Survey has had inquiries from large users of electrical insulators, particularly those used on high-tension transmission lines, as to the possibility of manufacturing such wares in Kansas from native raw materials. As stated previously, ball clay, stoneware clay, and siliceous fire clay consisting of a natural mixture of ball clay and powdered silica, are all available in Kansas for the manufacture of electrical insulating ware. There is a definite need for the manufacture of such products in Kansas. It would be necessary, however, for the prospective manufacturer to determine whether or not the volume of sales would be sufficient to support a plant of sufficient capacity to insure efficiency in operation.

The Geological Survey has also had a number of inquiries from clay products producers who wished to buy raw clay. At least two of these producers have stated that they would purchase clay in fairly large quantities if they could be assured continuous and uniform shipments.

LANDOWNERS AND LOCATIONS OF CLAY DEPOSITS

Table 26 gives the index number of locations from which clay was sampled during the systematic field survey of the Dakota formation in 1938 to 1941.

The clay locations sampled are listed in alphabetical and numerical order. Initial letters of clay location numbers indicate the county. For example "C" indicates Cloud County, "El" indicates Ellsworth County, and "L" indicates Lincoln County. The numbers given indicate location. The sample index number "C-1," for example, is equivalent to Cloud County (county "C"), SE¼ SE¼ sec. 32, T. 7 S., R. 2 W. (location "1"). The columns to the right of the index number of the location give the name of the landowner, the legal description of the location, and the thickness of beds sampled according to fired color, with the total thickness of clay sampled at the extreme right. The fired colors are arbitrarily divided into white, ivory to cream, buff, pink to dark buff, and red. Actually an infinite variation in color is possible within the limits given. Furthermore, many of the colors such as brown and lavender pinks do not fit the color range given. Light browns, for example, are classed with dark buffs, and dark browns with the red. White is never snow white, but faintly tinged with gray or ivory. In addition, the fired colors of the clays vary with the temperature at which they are fired. In this list the color of the clay chosen to be included was the one which resulted from firing to the temperature most practical for commercial use.

In the 11 counties listed, 10,497.6 feet of clay was sampled. If all the beds sampled occurred in one vertical face they would represent a cliff nearly 2 miles high. White clay comprises only 152 feet of this total thickness, ivory to cream 1,793.6 feet, buff 3,021.5 feet, pink to buff 2,027.1 feet, and red 3,535.4 feet. About 47 percent of the beds sampled fired to buff or lighter than buff colors. If all clay beds that occur in the Dakota formation had been sampled the buff or lighter colors would have represented only about one-third of the total. In our field work we attempted to select for sampling deposits in which a maximum thickness of the lighter firing clays occurred. In some cases thick and extensive beds of red-firing clay were omitted from the sampling because of their relative unimportance. Also clay beds lying below drainage, or under an overburden exceeding about 8 feet were omitted because of the impossibility of digging pits deep enough to obtain adequate samples. This selection accounts for the difference between the clays as sampled, and as they occur.

TABLE 26—*Landowners and locations of clay deposits, with fired color and thickness of beds sampled.*

Loc. Index No.	Land Owner	Location	Fired color and thickness in feet: White	Ivory to Cream	Buff	Pink to Dk. Buff	Red	Total depth sampled
			CLOUD COUNTY					
C-1	W. M. Walno	SE SE 32 7 2W					17.7	17.7
		SW SW 33 7 2W						
C-2	Elvina LaPlant	SE SE 14 8 2W		6.7			16.4	23.1
C-3	C. E. Emick, agt.	E½ 10 8 1W				32.1		32.1
C-4	Geo. Ahrendes	W½ NE 19 8 1W				15.2	11.0	26.2
C-5	E. J. Regnier	NE 14 8 2W		6.8	2.4	22.0	20.2	51.4
C-6	E. J. Regnier	N½ SE 14 8 2W			11.0		6.2	17.2
C-7	Elvina LaPlant	N½ SE 14 8 2W			7.9		8.1	16.0
C-8	E. C. Lacy	SW SE 14 8 2W		17.3	8.6	6.4	23.4	55.7
C-9	E. C. Lacy	N½ NE 23 8 2W		2.4	3.2	6.9		12.5
C-10	H. K. Pokomey	SW 15 8 2W			5.2			5.2
C-11	Seth H. Smith	W½ NE 11 8 2W					22.3	22.3
C-12	B. H. Lilliman	NE SE 11 8 2W		11.4	10.3		36.0	57.7
C-13	Jos. P. Lewis	N½NW 13 8 2W			7.8		32.5	40.3
C-14	W. L. Babbitt	W½ NE 13 8 2W						
		NW SE 13 8 2W			3.4		95.8	99.2
C-15	Henry B. Parsons	SW SE 13 8 2W					25.1	25.1
C-16	Chas. A. Procter	W½SW 16 8 1W		6.0			9.6	15.6
C-17	Leslie Collins	S½ SE 28 7 2W					9.6	9.6
C-18	Roch Lanoue	NW 34 7 2W			3.2		10.6	13.8
C-19	Aug. Odette	NW 23 7 2W		5.6			11.7	17.3
C-20	Ulysses Regnier	NE 15 7 1W			3.6	5.7	37.2	46.5
C-21	Jacob Haist	E½ SW 11 7 1W				8.7		8.7
C-22	C. V. Simpson	NW 9 8 2W					34.3	34.3
C-23	C. E. Emick	NE 22 8 2W			6.0			6.0
C-24	L. B. Hauck	S½ SE 19 8 1W					21.9	21.9
C-25	A. R. Tucker	E½ SE 29 8 2W				24.7		24.7
C-26	C. E. Emick	NE 8 8 2W					8.6	8.6
C-27	P. L. McBane	E½ SW 32 8 2W						
		NW 32 8 2W		49.6		10.7		60.3
C-28	C. N. Sharp	S½ 18 8 1W		7.6			25.6	33.2
C-29	D. Fortin	NW 31 8 1W		5.5				5.5
C-30	A. Fortin	SW 31 8 1W				6.0		6.0
C-31	Alva N. Watkins and							
	Susan E. Umphries							
	Geo. H. Palmer, agt.	S½ SE 2 8 2W			9.0			9.0
C-32	C. V. Simpson	S½ SE 5 8 2W			13.2		17.1	30.3
C-33	Donald McHenry	NE NE 27 6 2W			3.3	9.8		13.1
C-34	James Callahan	SW NE 11 8 3W			4.7			4.7
C-35	James Callahan							
	Arthur Hay	W½ SW 6 8 2W						
	J. D. Henderson	C.E½E½ 1 8 3W		11.3			8.1	19.4
C-36	H. S. Rice	W½ SE 28 8 3W					19.9	19.9
C-37	Joe Haist	SW 27 8 3W			4.2			4.2
C-38	R. C. Wrench	SE NE 33 8 3W			18.5			18.5
C-39	Mildred A. McCarrel	NE 20 8 3W			8.0		6.7	14.7
C-40	Fay L. Everitt	N½ SE 5 6 3W					3.5	3.5
C-41	Samuel McClain	NW SW 11 8 3W			6.0			6.0
C-42	R. L. Richard	SE 17 7 2W		3.3			5.8	9.1
C-43	Michael L. Lynch	NW NE 15 8 3W		5.6	4.4			10.0
C-44	Martin Flynn	SW 3 8 3W	5.2	5.0				10.2

TABLE 26—*Landowners and locations of clay deposits, with fired color and thickness of beds sampled, continued.*

Loc. Index No.	Land Owner	Location	Fired color and thickness in feet: White	Ivory to Cream	Buff	Pink to Dk. Buff	Red	Total depth sampled
C-45	H. J. Richard	W½ NW 10 8 3W				5.2		5.2
C-46	Ralph Weaver	NE 13 8 3W						
	Ray Davis	N½ NW 13 8 3W		6.3				6.3
C-47	F. J. Hurley	NW 14 8 4W						
C-48	Fred P. Chilen	SE 25 8 2W			6.7			6.7
C-49	G. W. Campbell	NW 6 5 2W			4.9			4.9
C-50	C. E. Emick	SW 34 8 2W					6.0	6.0
C-51	Chas. S. Cook	NW NW 12 6 3W		8.2	33.0	32.0	10.3	83.5
		Cloud Co. total	5.2	166.8	221.5	227.4	571.3	1182.4
		ELLSWORTH COUNTY						
*TC-1	Frank Mullen	NE SE 14 15 6W		24.6	6.2		7.4	38.2
TC-2	Frank Mullen	SE 15 15 6W		17.5	43.6		23.3	84.4
TC-3	Ed Mullen	NE 22 15 6W		29.7				29.7
TC-4	Ed. Cole, Sr.	NE SW 14 15 6W	3.0	34.0	5.8	12.1	12.4	67.3
El-1	John Vanier	S½ 11 15 6W		18.5	18.7		38.4	75.6
El-2	John W. Cleverdon	S½ 10 15 6W		24.9	14.8	19.7		59.4
El-3	Joe E. Straka	SE 9 15 6W		4.4	19.2	47.2	24.6	95.4
El-4	W. R. Lewis	SW 30 15 8W		6.6	19.7	28.4	17.9	72.6
El-5	Frank Hochman	NW 31 15 8W		13.5		8.3	15.6	37.4
El-6	G. Svaty	SW 31 15 8W		4.4		5.8		10.2
El-7	Mrs. Mabel Harts	NW 1 16 9W		6.0	3.2		13.8	23.0
El-8	Citizens State Bank	SE SE 2 16 9W		3.2		17.0	5.5	25.7
El-9	Paul L. Aylward	NE 11 16 9W		4.9	8.0	15.2		28.1
El-10	Mary Zavesky	S½ NE 28 15 8W		5.5			8.7	14.2
El-11	A. F. Cross	NW 36 15 6W		21.3		3.5	19.6	44.4
El-12	Geo. R. Allan	29 15 6W		12.0	22.7		4.2	38.9
El-13	W. M. Webster	5 16 6W	2.8	21.3	12.8			36.9
El-14	Mrs. Frank A. Bates	25 15 7W	1.5	29.1	43.7	6.3	10.9	91.5
El-15	John W. Cleverdon	NE 15 15 6W	2.6	11.7	27.4	10.7	18.0	70.4
El-16	Schultz Bros.	NE 6 16 8W		9.8	16.7			26.5
El-17	C. A. Gregory	25 16 9W			20.8		13.1	33.9
El-18	E. S. Leonard	SW 13 17 8W		6.0		30.9		36.9
El-19	Dr. C. O'Donnell	SE 24 16 9W				9.7	39.1	48.8
El-20	C. A. Andrews	SW 29 15 7W						
		NW 28 15 7W	10.7	50.5	29.1	11.5	33.2	135.0
El-21	Ind. Salt Mine	NW 29 15 7W						
		W½ NE 29 15 7W						
		E½ SW 20 15 7W		42.2	22.1			64.3
El-22	Curtis Lawson	S½ 1 16 7W		8.2	13.0		41.2	62.4
El-23	M. M. Rathbun	NW 8 17 8W			16.0		26.4	42.4
El-24	Robert B. Hudson	S½ NW 28 16 7W			7.6		13.6	21.2
El-25	Sherman Ranch J. H. Wilson, Mgr.	C. S½ 2 17 7W		5.9				5.9
El-26	H. Tappendick	S½ 13 15 9W			8.0	11.0	5.0	24.0
El-27	William Gregory	W½ 17 14 6W			15.9			15.9
El-28	Stella R. Bradford Minnich	W½ 21 14 6W			36.2			36.2
El-29	Harry Remley	W½ 23 14 7W		24.5	3.3	13.5		41.3
El-30	J. B. Sheridan	SE 13 15 7W			11.1	23.5	13.4	48.0
El-31	Frank B. Sheridan	W½ SW 17 15 6W			25.7			25.7

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*TC indicates Terra Cotta area in Ellsworth County.

El-32	Frank B. Sheridan		21	15	6W						
	F. E. Wires	S½ SE	16	15	6W		3.5	51.9	14.7	43.2	113.3
El-33	Carl Black, Sr.	NW	33	15	7W			8.4			8.4
El-34	A. F. Cross	SW	31	14	10W		1.2	19.8	4.9	3.3	29.2
El-35	Anna Adamek	SE	35	15	10W		6.5	18.2	5.5	19.1	49.3
El-36	Dr. C. O'Donnell	NE SW	33	15	8W		10.5				10.5
El-37	Tobias Doubrava	NW	1	16	10W		20.4	8.5	18.2		37.1
El-38	Martin Hochmans	SW	10	16	9W						
		NW	15	16	9W		19.9	10.8		16.5	47.2
El-39	Frank J. Jurenka	W½ NE	36	15	10W			12.6	8.2	7.7	28.5
El-40	Charles F. Urbanek	W½ SW	26	15	10W		15.2	22.5	11.1	16.9	65.7
El-41	W. Neuschafer	NW	6	16	9W		9.0		3.8		12.8
El-42	James Shanelec	SE	29	15	9W		10.5	4.3		2.6	17.4
El-43	Veat Jilka	N½ NE	25	15	10W		21.0	12.1	8.3	7.3	48.7
El-44	G. G. Smischny	SW	25	15	10W		8.2	3.6	10.9	10.5	33.2
El-45	Walter Brown	W½	19	15	9W		7.8	9.7	9.8		27.3
El-46	A. F. Cross	SW	36	15	6W		6.9	22.4		9.9	39.2
El-47	A. F. Cross	NW	25	15	6W			20.1		14.1	34.2
El-48	A. F. Cross	NE	36	15	6W		3.5				3.5
El-49	Friend Hoover	NW	7	16	8W			16.9	18.1	24.9	49.9
El-50	Carl Pflughoft	NE	5	16	8W		5.2		8.1		13.3
El-51	H. F. Huseman	E½	14	16	8W		16.3			14.2	30.5
El-52	Chas. E. Reed	NW	19	16	7W		2.8			21.5	24.3
El-53	Frank Shanelec	W½	25	15	9W		3.5	33.0			36.5
El-54	Louis Katzenmeier	NW	4	16	9W		20.3	3.0		36.4	59.7
El-55	W. Neuschafer	SE	31	15	9W		7.5	5.7			13.2
El-56	Otto Katzenmeier	NE	31	15	9W		8.5	20.1	3.7		32.3
El-57	Frank Neuman	SE	19	15	9W		20.6	25.7	6.4		52.7
El-58	Louis Katzenmeier	W½	2	16	9W		19.7	33.8		8.9	62.4
El-59	Frank Neuman	SE	19	15	9W		22.1	7.8			29.9
El-60	Walter Brown	SW	19	15	9W	8.4	15.9	21.1		9.7	55.1
El-61	Mary Zavesky	NE	19	15	9W		12.2	29.2	4.4	5.3	51.1
El-62	Louis Katzenmeier	NE	4	16	9W		4.0		2.4	1.8	8.2
El-63	George Katzenmeier	SE	5	16	9W		8.7	25.7	5.9		40.3
El-64	W. H. Cochrane	NW	22	16	8W						
El-65	Arthur C. Soukup	SE	22	16	8W		6.4	17.3	8.1		31.8
El-66	J. H. Long	NE	34	16	8W			14.2			14.2
El-67	E. H. Hodgson	SE	32	16	8W			21.8		32.3	54.1
El-68	Ben H. Cook	SW	18	15	6W			6.4	10.6	33.9	50.9
El-69	Sam Johnson	W½ NW	30	15	6W		9.5				9.5
El-70	John Vanier	W½ SE	14	15	6W						
El-71	John Vanier	NW	13	15	6W						
El-72	Ciril Vanek	S½	19	15	6W	6.5	3.8	10.6	5.8	25.2	51.9
El-73	W. H. Thornburgh	S½	19	14	7W	21.6	12.6	16.9	6.0		57.1
El-74	Fred E. Eilrich	SE	30	14	7W		7.2				7.2
El-75	George Alden, Sr.	S½ SE	30	15	8W	5.5		44.1	23.0		72.6
El-76	F. D. Rozelle	E½	21	16	8W	4.0		7.4	34.7		46.1
El-77	L. E. Shade	N½ NE	28	15	8W			3.2			3.2
El-78	John Pankan	NE	30	14	7W		14.7	10.5		5.0	30.2
El-79	William Gregory	NE	8	14	6W						
El-80	William Gregory	S½	7	14	6W		13.3	2.5	20.4	20.9	57.1
El-81	William Gregory	NW	19	14	6W	2.5				32.9	35.4
El-82	H. J. Buzick, Sr.	NW	6	14	6W		10.6	33.4	20.4	19.4	83.8
El-83	Gus Plinsky	NE	24	14	8W				4.0		4.0
El-84	W. H. Thornburgh	E½	5	14	7W		3.9				3.9
El-85	Mrs. Minnie Haden	NE	2	15	7W						
		SE	35	14	7W	5.9	7.6	9.1			22.6
El-86	W. F. Huseman	SE	21	14	7W						
El-87	Carl Eilrich	NW	5	15	8W		13.6	7.3			20.9
El-88	R. J. Eilrich	SE	5	15	8W					17.1	17.1

TABLE 26—*Landowners and locations of clay deposits, with fired color and thickness of beds sampled, continued.*

Loc. Index No.	Land Owner	Location	Fired color and thickness in feet					Total depth sampled
			White	Ivory to Cream	Buff	Pink to Dk. Buff	Red	
El-89	Chas Draigemeier	NE 24 15 7W						
	E. M. Carr	NW 24 15 7W		9.0		9.3		18.3
El-90	Ciril Vanek	S½ 19 15 6W	3.0		19.8			22.8
El-91	W. E. Soldner	NW 33 14 7W		50.2	23.0			73.2
El-92	W. H. Thornburgh	SE 29 14 7W		5.7				5.7
El-93	Bert Harmon	N½ 32 16 8W			4.4			4.4
El-94	B. C. Gray	SE 14 17 8W		7.6	15.3		4.6	27.5
El-95	A. J. Sharp	SW 18 17 7W			8.4		13.1	21.5
El-96	Mrs. Eliz. Hunter	NW 19 17 7W		13.4	4.0		5.2	22.6
El-97	Fred W. Huseman	SW E½ 17 17 7W		4.2				4.2
El-98	D. M. Campbell	S½ SW 20 17 7W		5.4				5.4
El-99	Mrs. H. F. Janssen	NW 25 17 8W			4.0			4.0
El-100	W. H. Grubb	W½ NE 34 17 6W					7.5	7.5
El-101	J. W. Major	NE 34 17 7W	10.3	3.6				13.9
El-102	George Little	NW 34 15 7W		9.2	5.2		5.4	19.8
		Ellsworth Co. total	88.3	963.1	1207.0	561.0	901.6	3701.0
		FORD COUNTY						
F-1	Henry Fredelake	NW NW 30 25 23W		13.8				13.8
F-2	Mrs. J. Speckart	NE 25 25 24W		6.5			7.8	14.3
F-3	Martha K. Shepard	SW SW 19 25 23W		6.8				6.8
F-4	G. Russell Cheaney	S½ SW 12 25 24W		9.9	7.4		3.2	20.5
F-5	A. E. Holladay	NE 12 25 24W			1.1			1.1
F-6	A. E. Holladay	SW SE 7 25 23W			9.1			9.1
F-7	Mrs. E. G. Hain	NE NE 20 25 23W						
	E. L. Herzer	NW 21 25 23W			12.5			12.5
		Ford Co. total	0.0	37.0	30.1	0.0	11.0	78.1
		HODGEMAN COUNTY						
H-1	Mrs. Emma S. Perry	S½ 24 22 22W		7.0	16.3		5.3	28.6
H-2	J. C. Hann	SE 26 22 22W			6.4			6.4
H-3	Hanston State Bank	SW 8 23 22W						
		NW 17 23 22W			8.1		5.5	13.6
H-4	Jennie, Ferlyn, Marlyn Korf	SW 7 23 22W			6.1			6.1
H-5	Fed. Land Bank	NW 12 24 23W			10.8			10.8
		Hodgeman Co. total	0.0	7.0	47.7	0.0	10.8	65.5
		LINCOLN COUNTY						
L-1	Robt. A. Hilgendorf	N½ NE 30 12 7W			32.9	7.5	19.0	59.4
L-2	W. O. Lebien	SE 31 12 7W			12.5	4.5	5.5	22.5
L-3	H. Knuckenberg	NW 32 12 7W			17.4	13.1	2.9	33.4
L-4	J. A. Parks	NW 36 11 7W			29.8	40.7	50.2	120.7
L-5	Farmers Alliance Insurance Co.	NW NW 15 12 6W			14.5	3.0	4.2	21.7
L-6	Clarence Smith	N½ SE 1 11 6W		4.0	12.6	46.6	20.3	83.5
L-7	A. B. Woody	NW 19 10 6W		10.9	16.6	7.1	5.3	39.9
L-8	C. E. Meyers	NW 33 10 6W		8.0	7.8	13.6	46.7	76.1
L-9	G. H. Boston	SW 33 13 7W	7.0	32.3	55.9	15.7	32.9	143.8
L-10	Ferdinand Wacker	W½ NW 10 13 7W		25.9		4.7	33.0	63.6
L-11	George Meier	SW 10 13 7W		5.0	4.4			9.4
L-12	E. W. Aufdemberge	S½ NW 34 12 7W			5.3	4.0	6.2	15.5

L-13	Fred White	N½ NW	34	13	7W		4.4		8.0	37.2	49.6
L-14	Alex Jackson	SE	31	10	6W			3.0	16.9	29.3	49.2
L-15	W. A. Trapp	NE	7	13	6W				17.5	21.1	38.6
L-16	Jacob Pfeifer	NE	17	13	6W		2.7		12.6		15.3
L-17	Mrs. C. F. Shafer	NW	5	13	6W		4.5		3.8	6.3	14.6
L-18	John Urban	SE	18	13	6W		7.1				7.1
L-19	C. O. Atwell	SE	29	10	6W				10.7	25.2	35.9
L-20	Ella H. Bryce	SW cor.	30	11	7W		5.2	3.4	13.8		22.4
L-21	Mrs. Vera Eutsler	NW	15	13	6W		5.0		4.7	24.6	34.3
L-22	Grant Tozier	W½ SW	36	11	6W				8.1	32.1	40.2
L-23	G. W. Sorenson	NE	19	10	7W			5.3		12.6	17.9
L-24	O. O. Richards	SE	7	13	6W			4.5	4.9	12.4	21.8
L-25	F. C. Kaul	W½ SW	18	10	6W			8.5	31.2		39.7
L-26	Mrs. Oral Myers	SE	32	10	6W		2.6			9.6	12.2
L-27	Fred Eggle	SE	8	13	6W		10.0	5.0	1.7	20.6	37.3
L-28	Frank O'Neill	SW	22	10	6W						
L-29	Irena O'Neill	W½	28	10	6W			10.0	12.1	40.6	62.7
L-30	E. M. Snook	NE NW	32	10	6W	0.6	1.7		8.4	7.0	17.7
		NW NE	32	10	6W						
L-31	Noah Scott	E½ SW	4	12	6W			24.8			24.8
L-32	F. W. Pfeifer	NW	23	13	6W			10.4		11.0	21.4
L-33	Mrs. A. M. S. Clark	SW	10	12	6W		6.8		26.1	5.8	38.7
L-34	John J. Lambert	SE	30	12	10W			9.8	6.3		16.1
L-35	John J. Lambert	NW	31	12	10W		33.2		4.3	19.3	56.8
	Frank Barta	SW	31	12	10W						
L-36	John J. Lambert	SW	19	12	10W						
L-37	John J. Lambert	NE	19	12	10W		7.9				7.9
L-38	John J. Lambert	NE	19	12	10W		10.6	3.7		3.2	17.5
L-39	M. J. Watkins, Agt.	NW	18	13	10W	12.3		3.6			15.9
L-40	M. J. Watkins	SW	18	13	10W			18.6	2.0	34.2	54.8
L-41	M. J. Watkins	NW	18	13	10W			13.1		7.8	20.9
L-42	M. J. Watkins	SW	18	13	10W	9.7	15.6		3.5	8.4	37.2
L-43	Eliz. O. Weber	NE	29	13	10W		8.0	7.4	15.7	6.6	37.7
L-44	Floyd Britt	NW NW	13	12	10W		7.9		5.8		13.7
L-45	Louis Serrien	N½	15	12	9W		5.0	19.7	3.7	12.0	40.4
L-46	Louis Serrien	N½	15	12	9W					10.5	10.5
		Lincoln Co. total				29.6	224.3	360.5	382.3	623.6	1620.3

OTTAWA COUNTY

O-1	F. E. Chapin	SE	33	10	5W		3.6	4.7		15.4	23.7
O-2	E. J. Minneman	SW NE	18	12	4W		8.3			21.0	29.3
O-3	C. H. Stormont	SE	14	11	4W						
O-4	Elmer McClellan	NW	14	9	5W		5.4	37.7	3.1	12.7	58.9
O-5	J. R. Veal										
	Boyd Baker, lessee	NE	18	11	4W		8.7	8.1	18.7	7.8	43.3
O-6	Isaac Briggs	S½ SE	5	9	2W		8.6				8.6
O-7	Claude H. Norris	SW	4	9	2W		1.8		14.2	10.2	26.2
O-8	A. C. Perry, Sr.	SW	7	12	4W		4.1		10.3	9.3	23.7
O-9	F. W. Reed	W½ NW	20	12	4W					17.7	17.7
O-10	J. F. Gamber	SW	21	12	4W					16.8	16.8
O-11	H. B. Cumberland	NW	29	12	3W		2.2		12.8	3.0	18.0
O-12	H. E. HcCullick	E½ SE	30	12	3W			4.0	3.5	4.3	11.8
O-13	Anna Breithaupt	W½ SE	30	12	3W					18.6	18.6
O-14	H. E. McCullick	NE SW	32	12	3W			6.1		13.5	19.6
O-15	C. H. Eikelberger	SW	11	12	4W					32.3	32.3
O-16	Carl Nelson	SW	34	11	5W			4.0	4.5		8.5
O-17	Ira W. McCall	SW NE	31	12	3W			0.8		7.0	7.8
O-18	Sam Andrews	NE	30	12	3W			6.2		7.8	14.0
O-19	James F. Pitts	SE	26	12	4W					10.9	10.9
O-20	Mrs. Elmer Duggan	W½	4	12	1W			21.6	17.9	3.1	42.6

Table 26—*Landowners and locations of clay deposits, with fired color and thickness of beds sampled, continued.*

Loc. Index No.	Land Owner	Location	Fired color and thickness in feet					Total depth sampled
			White	Ivory to Cream	Buff	Pink to Dk. Buff	Red	
O-21	Mrs. Frank Duggan	SW 34 11 1W			14.7		13.5	28.2
O-22	I. E. Barringer	SE 25 11 2W			5.7		16.0	21.7
O-23	Arthur Smith	NW 10 11 1W			11.0			11.0
O-24	William Millen	SE SW 20 12 2W			2.8		3.6	6.4
O-25	James Greenough	NE 4 12 1W			4.5	24.9		29.4
O-26	J. C. Hoover	NW 1 11 1W			2.5		22.2	24.7
O-27	J. F. Shroyer	21 9 2W		10.3	13.3		80.9	104.5
O-28	A. R. Tucker	NW 10 9 2W		4.0	6.6		8.0	18.6
O-29	Paul Wilkins	SW 10 9 2W			12.5	16:6	19.2	48.3
O-30	F. J. Hogan	SE 8 9 2W			6.8	5.8	14.4	27.0
O-31	Alfred Akerman	NE 7 9 1W						
	W. R. Catlier	SE 6 9 1W		5.0		23.5	11.8	40.3
O-32	T. A. Cooper	Cen. 34 9 2W					18.8	18.8
O-33	Ray Engler	SE NE 8 9 2W			5.5	9.7	13.5	28.7
O-34	W. H. Hays	NW 7 9 1W		6.3	13.7		21.0	41.0
O-35	W. W. Fuller	NW 2 9 2W			22.4		8.8	31.2
O-36	O. C. Hale	NE 12 9 3W		3.8		5.6	15.1	24.5
O-37	R. H. Baggerly	N½ NE 14 9 3W		2.2			22.4	24.6
O-38	I. Briggs, lessee	NW NE 8 9 2W		9.1		13.4		22.5
O-39	Mrs. L. E. Dudley	NW 4 9 3W						
	Claude Winsett	NE 4 9 3W			18.3	19.1	8.2	45.6
O-40	Emma F. Blackmer	N½ SE 5 9 2W		14.7				14.7
		S½ 5 9 2W						
O-41	Fred J. Bowen	SE 11 10 1W			15.1		4.2	19.3
O-42	T. E. Frain	SW 26 11 4W				23.5		23.5
O-43	J. C. Reed	SE 26 11 5W		1.4	7.8	2.3		11.5
O-44	Louis E. Lee	E½ SE 8 11 4W				11.8		11.8
O-45	J. J. Allen	NE 6 11 4W			19.3		7.0	26.3
O-46	J. P. White	NE NW 29 10 5W					5.3	5.3
O-47	Lee W. Skinner	NE SE 11 9 5W						
O-48	Oscar Schlotz	SW 17 11 4W			20.1	9.6		29.7
O-49	Ottawa County	SW NW 25 11 4W		12.6		7.3		19.9
O-50	J. C. Reed	SE 26 11 5W						
		Ottawa Co. total	0.0	112.1	295.8	258.1	525.3	1191.3
		REPUBLIC COUNTY						
RP-1	Otis J. Kasha	NW 17 4 1W		2.6	13.1	9.3	25.8	50.8
RP-2	S. R. Haudek	NW 8 4 1W		3.2	7.6	2.0		12.8
RP-3	Milo Benyshek	SE 32 3 1W			3.0	6.2	4.6	13.8
RP-4	Milo Benyshek	SE 32 3 1W			2.7	6.1	2.6	9.4
RP-5	Edward Kolman	SW 29 3 1W			3.6	6.7		10.3
RP-6	Leon L. Junek	SE SW 27 3 1W			3.3		6.4	9.7
RP-7	Lawrence Hard	NE NW 34 3 1W					21.8	21.8
RP-8	M. B. Haudek	SW 11 4 1W					21.9	21.9
RP-9	M. B. Haudek	NE 23 4 1W			15.9			15.9
RP-10	Joseph M. Lindell	SE 11 4 1W				4.5	31.4	35.9
RP-11	Joseph M. Lindell	SE 11 4 1W			13.0		18.3	31.3
RP-12	Chas. Potuzak	NE 19 4 1W				12.3		12.3
RP-13	E. R. Cousins	C. of N. line						
		NW SW 7 4 2W		4.2	6.3			10.5
RP-14	D. S. Dewey	SE NW 7 4 2W			10.9			10.9
		Republic Co. total	0.0	10.0	79.4	47.1	132.8	267.3

RICE COUNTY

RE-1	E. H. Hodgson	NE	1	18	6W				6.7		6.7
RE-2	E. H. Hodgson	SE	3	18	6W					8.8	8.8
RE-3	E. R. Kenyon	NE	10	18	6W			1.6			1.6
RE-4	R. R. Newkirk	SE	11	18	7W					8.2	8.2
RE-5	Mrs. Helen Harris	SE NW	13	19	7W					8.2	8.2
RE-6	T. J. Moll	S½ SW	16	20	6W		5.0				5.0
		Rice Co. total				0.0	5.0	1.6	6.7	25.2	38.5

RUSSELL COUNTY

R-4	John J. Lambert	NW	36	12	11W		15.0	38.8	9.3	19.8	82.9
R-5	John J. Lambert	NW	25	12	11W		10.1	23.7	11.0	16.8	61.6
R-6	John J. Lambert	NW	25	12	11W	4.2	19.4		29.4	5.5	58.5
R-7	John J. Lambert	SE	24	12	11W				27.2		27.2
R-8	John J. Lambert	SE	24	12	11W		8.4	8.0	20.6	27.4	64.4
R-9	Joseph A. Vanek	NW	12	13	11W			12.1		13.0	25.1
R-10	Helen Kuck	SE	12	13	11W			11.5	17.5		29.0
R-11	E. G. Coffey	SE	13	13	11W			29.0	6.9		35.9
R-12	Mrs. C. F. Nelson	NE	13	13	11W			8.3		27.6	35.9
		Russell Co. total				4.2	52.9	131.4	121.9	110.1	420.5

SALINE COUNTY

S-1	Elmer E. Carlson	NW	29	15	4W				4.6	32.3	36.9
S-2	L. E. Sharer	W½ NW	10	15	5W			12.3		28.3	40.6
S-3	Edwin Johnson	NE	30	15	4W		5.3	17.6	18.1	4.7	45.7
S-4	W. L. Tate	N½	18	15	5W						
		SE	18	15	5W		4.6	16.5		64.5	85.6
S-5	R. J. Laubengayer	NE	30	15	5W		4.5	6.7	3.2	6.1	20.5
S-6	R. J. Laubengayer	NW	31	15	5W		8.5	44.1		9.8	62.4
S-7	Lindquist Farm	SW	6	16	5W			3.3	6.8	48.6	58.7
S-8	W. L. Tate	SE	5	15	5W				13.3	17.3	30.6
S-9	W. L. Tate	NW	5	15	5W		3.8	5.9	9.5	28.8	48.0
S-10	N. J. Tate, owner F. H. Moorman, lessee	NE	6	15	5W		14.7	21.0		24.1	59.8
S-11	H. C. Schrader	NW	33	14	5W			9.1		15.9	25.0
S-12	H. C. Schrader	NE	33	14	5W			7.2		18.1	25.3
S-13											
S-14	Joe Soderberg	NW	7	16	5W		13.8	7.7	8.2	19.8	49.5
		Saline Co. total				0.0	55.2	151.4	63.7	318.3	588.6

WASHINGTON COUNTY

W-1	Oscar Violett	E½ SE	1	3	2E		14.4	11.1	12.2	1.1	38.8
W-2	Henry Burtram	SE	31	2	2E				39.3		39.3
W-3	W. A. Soller, Agt. for C. E. Brown	NW	14	2	3E	3.1	13.4	29.5	15.6	18.3	79.9
W-4	Rudolph Waser	NW	14	2	3E		3.0	7.4		8.0	18.4
W-5	Schley Brenneis	N½ SE	14	1	3E		4.0	11.6	8.3	4.7	28.6
W-6	Raymond R. Frager	E½ NE	13	2	2E				21.3		21.3
W-7	Columbus Jones	NW	15	2	3E	4.4		11.4	8.0	6.7	30.5
W-8	Theo. Buehler	N½	8	1	3E		2.8	20.1		4.4	27.3
W-9	L. Zimmerman	W½ NE	20	1	3E			13.5	8.7	21.8	44.0
W-10	Mabel A. Barr	SE SW	8	1	4E			8.8	10.0		18.8
W-11	Henry Burtram	SE SE	30	2	2E			16.7			16.7
W-12	A. C. Fuhrken	SW	27	3	3E			7.1	14.0	20.8	41.9
W-13	P.Z. & E.J. Gauvreau	SE	10	2	3E		3.1	3.5	37.4	4.7	48.7
W-14	Emmett Nutter	S½	19	1	3E		14.2	3.8	7.1		25.1
W-15	John Stamm	NW	3	3	4E					18.0	18.0
W-16	Mrs. M. Rose	SE SE	27	2	2E			8.8	21.1	6.6	36.5
W-17	Ernest Funke	SE NE	14	1	3E			9.6	37.7		47.3
W-18	W. P. Lovgren	W½ SE	5	1	3E		10.2		40.2		50.4

W-19	Wm. D. Meyer	SW	28	1	3E		17.7	11.2			28.9
W-20	F. C. Hirman	SE	28	1	3E						
W-21	Stanley Habr	SE	5	2	3E			38.6		19.9	48.5
W-22								12.0			12.0
W-23	Fred Lohmeyer	E½	4	4	3E		11.5		13.4		24.9
W-24	Mrs. E. V. Howland	E½ SE	8	1	3E		6.5	11.7		12.1	30.3
W-25	Emmet Nutter	N½	19	1	3E			12.9			12.9
W-26	J. Greiveldinger	W½ SE	3	2	4E			34.4		5.3	39.7
W-27	Frank Ruhlkamp	SW	2	2	4E						
W-28	L. W. Koehler	NW	36	2	4E						
W-29	Henry A. Goekel	SE	35	2	4E				13.7		13.7
W-30	Mary Cadwallader	SE	28	3	3E			16.2			16.2
W-31	Mrs. Eliz. Bishop	S½ SW	30	4	4E					23.1	23.1
W-32	Henry A. Nutsch	W½ NW	30	2	2E			5.9	21.0	13.5	40.4
W-33	C. A. Carlson	SE	27	2	1E			4.6		7.5	12.1
W-34	S. E. Church	NW SE	2	2	1E		7.4	7.5		7.9	22.8
W-35	W. L. Higgins	N½ NW	27	3	3E			4.0			4.0
W-36	Ed Cornwell	NE NW	34	2	1E					23.1	23.1
W-37	E. C. Wranosky	NE SW	22	2	1E					25.5	25.5
W-38	C. E. Rector	NE	5	3	4E				22.7		22.7
W-39	Ed Cornwell	N½ NE	34	2	1E						
	C. A. Carlson	SE	27	2	1E	6.8	10.7	12.3			29.8
W-40	W. J. Johnston	NW NW	34	2	1E			7.5			7.5
W-41	U. S. Lull	SW NE	27	2	1E			9.0			9.0
W-42	Mrs. Minnie Dovel	NE SW	26	2	1E						
W-43	Frank Moore, renter										
	F. E. Boylan, owner	E½SWSE	26	2	2E			35.1			35.1
W-44	Learn Bond	SW	3	2	4E						
W-45	Ed Banninger	E½ NE	17	2	1E						
W-46	William Voelker	E½ SW	26	5	3E			15.1			15.1
W-47	W. J. Gieber	NE	18	4	2E			13.3			13.3
W-48	Lester Meyer	NW	11	4	2E			11.3			11.3
W-49	Wilber Colgrove	SW SE	35	3	2E			12.5			12.5
W-50	O. C. Byrd	N½ SE	32	3	3E		4.0				4.0
W-51	J. T. Lewis	W½ SE	1	3	2E		8.2		8.3		16.5
W-52	G. B. Hicks	SE	18	3	3E						
	Albert Oliver	NE	18	3	3E		8.2	12.7			20.9
W-55	E. W. Beeman	SE	12	3	2E		15.5				15.5
W-54	Hannah Edwards	N½	20	3	3E			6.0			6.0
W-55	Frank Carlson	NW	6	4	2E			10.8			10.8
W-56	Arthur Harz	NW	5	4	2E	10.4					10.4
W-57	Agnes A. Wiltzius	E½ NW	13	5	1E			14.8	8.9		23.7
W-58	Roy Feight	NW	24	5	1E			4.5	4.0		8.5
W-59	J. L. O'Donnel	E½	31	2	1E			15.8			15.8
W-60	C. H. Jones	C. W½	6	3	2E				3.2		3.2
W-61	W. F. Kohlmeyer	NW	10	3	3E		2.6	13.1	9.3	25.8	50.8
*WP-1	W. H. Droegemueller	NW	8	2	5E					20.3	20.3
WP-2	Mueller Bros.	SE	5	2	5E					16.4	16.4
WP-3	Mueller Bros.	NW	32	1	5E						
WP-4	John F. Mueller	S½ SW	21	2	5E				15.5		15.5
WP-5	Herman Schmidt	N½ NE	31	1	5E						
WP-6	Frank Ruhlkamp	S½ SW	15	2	5E						
WP-7	Wes. A. Nesper	C.E½SW	28	2	5E						
WP-8	Margaret Cumro	NE SW &					11.0	12.4			23.4
		NW SE	9	1	4E						
		Washington Co. total				24.7	168.4	538.1	400.9	315.5	1427.6
		Total of 11 counties				152.0	1801.8	3054.5	2059.1	3545.7	10581.1

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*WP indicates Permian or Pleistocene beds sampled in Washington County; they are included because contiguous to Dakota formation clays in this area.

THE USE OF CLAY IN SMALL-SCALE PRODUCTION AND IN THE ARTS AND CRAFTS

The increasing popular interest in development of Kansas clay resources should in part be credited to the activities of the schools of the State. Classes in clay modeling and pottery-making have been extended and expanded within the past few years. As a result, an increasing number of persons have an elementary knowledge of ceramics and carry this knowledge and interest into their communities. Many of the graduates are now teaching classes in clay modeling and pottery making, whereas others have started small potteries or take part in community recreation work of which pottery making is an important part.

Schools, small-scale potteries, and individual craftsmen usually wish to use Kansas clay, and preferably clay which is obtained in the local community. Although many have been successful in obtaining and processing local usable clay, others have found it a difficult problem. This fact is attested by the scores of letters received each year by the State Geological Survey. In most cases small samples of clay are sent in to be tested for their suitability for pottery making. Other enquirers want to know where clay can be obtained or how to process it. Some of the inquiries relate to problems encountered in firing and glazing the pottery after it is made. The information given in this section of the report is intended to cover the field suggested by these inquiries received by the State Geological Survey.

HOW TO IDENTIFY USABLE CLAY

The novice in ceramics is inclined to think that clay suitable for making pottery or other fired articles is a rare material which can be obtained only from commercial sources, and that the more distant the source, the better the clay. This notion is entirely contrary to the facts.

Clay is the most abundant material on the surface of the earth. In Kansas, excepting a few unusually sandy areas, it is possible to walk but a few steps on the native earth without stepping on material which is chiefly clay. Although much of the clay which occurs at or near the surface is not suitable for use, it is possible to find amounts of usable clay sufficient for local use in the arts and crafts in almost any community of Kansas.

The suitability of a clay for use in making pottery or other articles can be determined by a few simple tests. To avoid loss of time in testing poor clays it is advisable to eliminate the obviously unsuitable ones by examining them at the outcrop. Most amateur clay hunters make their initial mistake by sampling only from the surface. Surface exposures of the highest grade clay are likely to be contaminated from various sources, particularly by material washed from higher elevations. In all cases the soft surface material should be removed until clay which is hard to dig out is encountered. Usually this surface material is not more than a foot thick, and is often less. The best exposures of clay are usually found along fresh road cuts and recently eroded creek banks.

A good pottery clay is smooth to the touch and to some extent can be rubbed to a polished surface with the thumb nail or the blade of a knife. It should be free from coarse particles such as sand, gravel, or chunks of lime. The sand and gravel are not as serious defects as the lime. Furthermore, lime may be in the finely divided state and, therefore, cannot be detected by visual inspection. To test for the presence of lime it is well to carry a small bottle of dilute hydrochloric acid (muriatic acid) with a medicine dropper stopper. The concentrated acid should be diluted with at least equal parts of distilled water. The acid should be applied to the clay with the medicine dropper and particularly to any light-colored hard chunks. If lime (calcium carbonate) is present the material will effervesce or "fizz." Such clays should not be considered for use.

In most cases clay in the natural state does not contain enough moisture to be completely plastic, but unless it is in the form of a hard shale, it contains enough moisture to permit pressing it into a ball in the hands. If the clay sticks together and feels plastic, it is probably workable.

The exposure selected for sampling should be carefully cleaned of soft surface clay and any loose material lying above should be removed to prevent contamination while sampling. The sample should be a trench of uniform width and depth across the entire thickness of the bed to be sampled. Not less than 10 pounds should be obtained for testing. Often samplers take out a few spoonsful of clay from one spot on the surface and are greatly surprised when clay obtained later in larger amounts from the same exposure is not the same as that tested. After the clay is sampled, the exact location and thickness of the bed sampled (the vertical distance from top to bottom, measured in feet and inches) should be noted on the container.

After obtaining the clay sample, it should be worked up by the methods described under how to prepare clay for use. The last step in the preparation of the clay is the removal of excess water. This is usually done by placing the slip on a dry plaster of Paris slab. The correct amount of water to leave in the clay can be judged by handling it. If it is too wet, it will be sticky and too soft to retain its form when molded in the hands; if too dry, the clay will crack when kneaded. When the clay is suitable for use, it should be possible to roll the clay into long ropes which will not break when bent. Clays which are sticky and tender when too wet, and which lack plasticity (that is, the capacity for being deformed, or molded into shapes without cracking or breaking) are not suitable for pottery making, but in some cases may be suitable for making pressed tiles, bricks, or similar solid shapes, or possibly for slip casting of ware.

Any one who has used a good pottery clay will immediately recognize a workable clay by the simple process of using it to make a piece of pottery or trying to model a small object. This should be the next step in testing a clay. The test piece, preferably a piece of pottery, or a small brick, should be dried in the open air, but not near a radiator or other source of heat. If the article dries without cracking or warping, the plastic and drying properties of the clay are probably satisfactory.

After the article has been dried thoroughly, it is ready for firing in the kiln. It is important that the last traces of moisture be removed before firing. The test piece should be fired to the temperature to which it will be employed in future work with the clay. This temperature usually ranges from cone 07 to cone 04 in the case of school and small-scale pottery kilns.

On firing, the clay will probably turn to a light orange or a brick red. If the clay is suitable for use, it will not have cracked, shrunk excessively, or have a scummed surface, and it should be nearly as hard as steel. After the piece is taken from the kiln it should be set aside for a few days. If there are any particles of lime in the clay, the particles will slake, and small pieces of the clay will pop out. If the clay contains an excessive amount of finely divided lime, it will fire to a light buff or a dirty white in which case the piece may fall apart after standing a few days. Such limy clays obviously are not suitable for use. In most cases the presence of lime can be detected by the use of hydrochloric acid, as described in preceding paragraphs. A clay containing a considerable proportion of lime may produce a sound brick or piece of pottery when fired, but the product is usually rather porous and does not take a glaze well. On the other hand, a small percentage of finely divided lime may be beneficial.

If the test piece is sound after standing a few days, its capacity for absorbing water should be tested. The dry piece should be weighed to an accuracy of 0.1 percent of total weight. The small balances used to weigh out glaze ingredients are usually sufficiently accurate for this purpose if the test piece weighs not less than 200 grams (about 7 ounces). The weight of the test piece should be recorded and the piece then completely immersed in water and the water heated to boiling point. After this procedure it may be allowed to cool but should remain completely immersed in water for at least 5 hours. The test piece should then be removed, the excess water wiped off with a damp cloth, and rapidly weighed on the same balance used to obtain the dry weight. The weight of the soaked test piece is the saturated weight. The percent absorption may be calculated by subtracting the dry weight from the saturated weight, dividing the difference by the dry weight, and multiplying by 100. The formula follows.

$$\frac{\text{Saturated Weight} - \text{Dry Weight}}{\text{Dry Weight}} \times 100$$

Example problem: Dry weight . . . 100 grams
Saturated weight 110 grams
$110 - 100 = 10$
$10 \div 100 = 0.10 \times 100 = 10\%$

If the absorption is not above 10 percent the clay has been fired to a sufficiently high temperature, although a smaller percentage of absorption is desirable. It is possible to fire clay to a point where the absorption is less than 1 percent. A clay body fired to an absorption of less than 3 percent may be termed stoneware. The absorption of a clay decreases with increasing temperatures. Some clays will absorb very little water when fired to cone 06, whereas others will have an absorption of more than 20 percent at the same temperature and may have to be fired to cone 14 or higher to reduce the absorption to 10 percent.

If one tests a clay which contains no lime, and which fires to a cream or buff color, he will have found a fire clay similar to those of the Dakota formation described elsewhere in this bulletin. Such clays are not of common occurrence and are much sought after by potters because the color of the body has less effect on the color of the glaze than is true of red-firing clays. Also, plastic-fire clays usually have a longer firing range. For example, some of the Dakota formation plastic fire clays have an absorption of less than 10 percent at cone 06, but may be fired to cone 10 without warping or becoming soft in the kiln. A good red-firing clay, however, should cause no trouble. In fact, it is much easier to find a red firing clay which fires to a hard, strong body at cone 06 to 04 than it is to find a buff-firing clay with similar properties. Many potters use buff-firing clays which are underfired at the temperature to which they fire their kilns. Leaking crazed ware is the inevitable result of this practice. An absorption test run on the bisque would reveal this error. In such cases, the only cure is to fire to a higher temperature or to use a different clay. If neither alternative is possible in special circumstances, a lean open-firing clay can be altered by any one of three methods. An extremely plastic dense-firing clay such as bentonite may be added to the clay in small amounts. Usually 3 to 10 percent is sufficient. The second method is that of beneficiation by sedimentation. This can be accomplished by mixing the clay to a thin or watery slip and allowing the silt and sand to settle to the bottom. The clay remaining in suspension can be siphoned or poured off and will be much more plastic and dense-firing than before. The length of time during which the clay is allowed to settle must be judged for each clay. The slip or suspension should be placed in a straight-sided glass container for first trials. The accumulation of coarse sediment can be observed by this method. A third method, and one commonly used, is that of adding a flux to lower the maturing temperature. The choice of flux to be used will depend on firing temperature and what the user can afford. Colemanite, water glass, soda ash, or a frit such as used in glazes is suitable for low temperature bodies. The percentage of the ingredient required can be determined by experimentation. Usually less than 10 percent frit or colemanite will be needed. It is advisable to try about 5 percent at first. Mr. Sheldon Carey conducted a series of experiments in which he added various amounts of colemanite to the buff-firing Kansas clay used by the students in the Department of Design at the University of

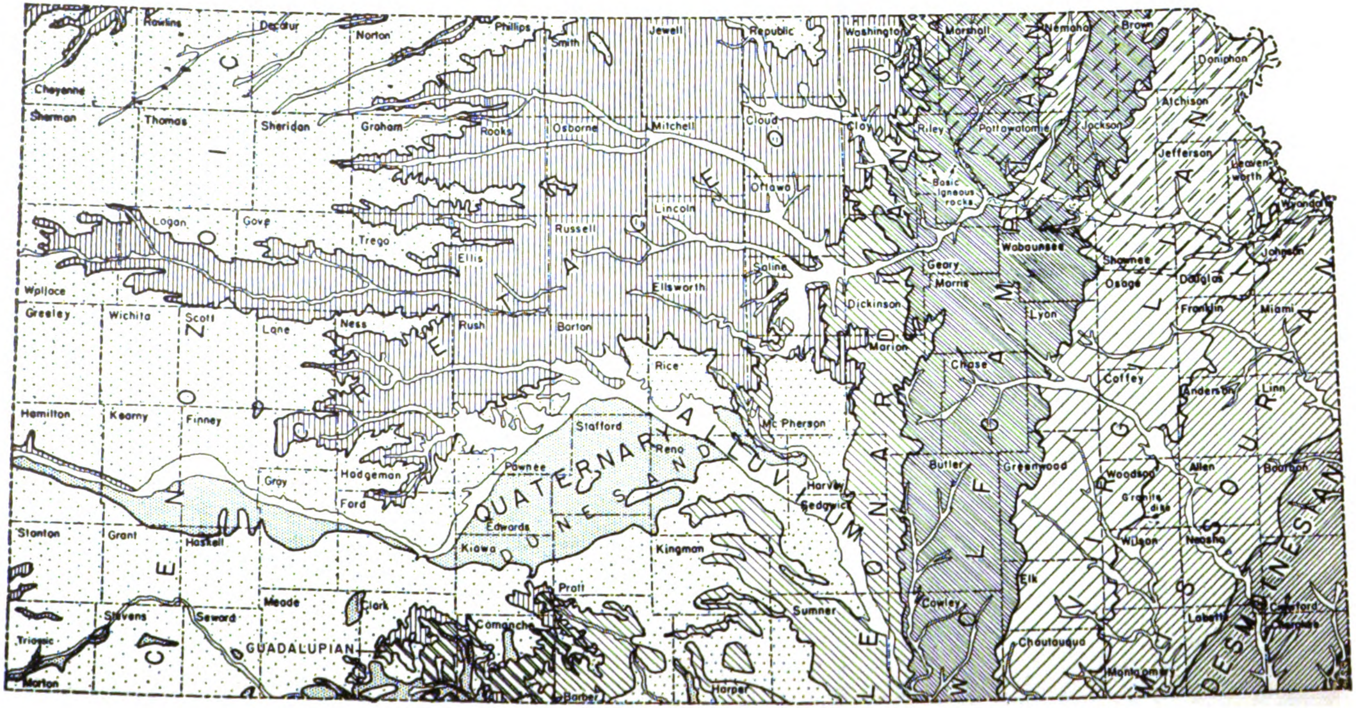

FIG. 17.—Map showing distibution of main divisions of outcropping rocks of Kansas, including Mississippian, Pennsylvanian (Desmoinesian, Missourian, Virgilian), Permian (Wolfcampian, Leonardian, Guadalupian), Cretaceous, and Cenozoic (includes Tertiary and Pleistocene) rocks.

Kansas. He found that about 4 percent colemanite was satisfactory for this particular clay (personal communication). The clay body they are using is a mixture of clays corresponding to our samples C-27-13a and TC-2-10. Three parts of the C-27-13a clay is mixed with one part of the TC-2-10 clay.

WHERE VARIOUS TYPES OF CLAY ARE FOUND

The types of clay available in any local community are limited and are determined by the geological history of the area. The various parts of the State in which the rocks of the chief geological ages are exposed at the surface are shown on Figure 17.

The oldest rocks exposed at the surface in Kansas are those of Mississippian age which crop out in a small area in the southeastern corner of the State. We have no record of usable clays of Mississippian age being found in Kansas.

The rocks of Pennsylvanian age were deposited on top of those of Mississippian age and are exposed at the surface over a wide area in the eastern third of the State. Enormous amounts of red-firing clay and shale and some buff-firing clay occur in this area. The majority of the brick and tile plants of the State are using Pennsylvanian shales or clay. (A shale, as we have used the term in this report, is a clay which breaks out in flat chunks, or flakes. A shale is usually somewhat harder than a massive clay, and slakes in water much more slowly.) The color of the Pennsylvanian clay or shale may be nearly black, gray, tan, greenish tan, yellow, or maroon. The black shale is usually not suitable for use because of the difficulty experienced in burning out the organic matter. Otherwise, there is very little relationship between the color and the quality of the clay. Calcareous (limy) shales and silty or sandy shales should be avoided. The defects of limy shales and the method of detecting them has been discussed in preceding paragraphs. The silty or sandy shale may lack sufficient plasticity for use and is likely to produce a porous body when fired.

It is advisable for one to look for a shaly clay rather than a soft massive clay in the outcrop area of Pennsylvanian rocks. The massive soft clays are usually formed by the weathering of shale and are in most cases contaminated by lime or other materials. One exception is found in the underclays, which are massive hard clays found beneath some of the coal beds of Pennsylvanian age. In some cases these underclays fire to a buff color.

Beds of Permian age overlie the Pennsylvanian rocks and are exposed in a wide belt extending westward from the western limits of the Pennsylvanian outcrop area to a point where they are covered by the overlying and therefore younger Cretaceous rocks. Less is known about the ceramic value of Permian clays and shales than those of Pennsylvanian age. Although we have discovered several beds of usable Permian shale, we have found that it is somewhat difficult to evaluate them from their appearance on the outcrop. This is because many of them contain fairly high percentages of finely divided silt, lime (calcium carbonate), or dolomite (a mixture of calcium carbonate and magnesium carbonate). Those high in dolomite may be usable whereas those high in lime are not. The dolomite does not produce popping or disintegration in the fired ware to the extent true of lime. Some of these dolomitic shales fire to a buff color and if fired carefully produce sound ware.

The color range of the Permian shales includes grays, greenish grays, and maroon. The maroon clays or shales usually contain less lime than those of other colors although they are almost certainly red-firing.

One shale which produces a brown glaze when fired to cone 8 to cone 12 has been found. This shale was sampled on the creek bank just north of the first bridge west of Johnstown, McPherson County.

Beds of Cretaceous age make up all the bed rock exposed west of the Permian outcrop belt. In keeping with the derivation of the name "Cretaceous," which is from the Latin word *Cretaceus* meaning "chalky," the majority of the Cretaceous beds are made up of chalk or chalky limestone and shale. The most valuable ceramic clays, however, are also of Cretaceous age. These clays are in the Dakota formation which is exposed at the surface in a belt extending across central and north-central Kansas and in small areas in southwestern Kansas. The exact area included is shown on the clay outcrop map (Fig. 1). The Dakota formation contains few limestone or limy clay beds so that there is little likelihood of one encountering the defects due to lime in the clay obtained from this formation. Sandstone and silt are quite common but too easily recognized to cause a searcher much trouble.

The color range found in the Dakota formation clays is wide and includes some rather vivid hues. Shades of gray, ranging from nearly black to nearly white, predominate. The grays in many beds are mottled or splotched with varying amounts of red, yellow, or lavender. The latter colors tend to produce some tint of red in the fired clay. The clays containing little or none of the red, yellow, or lavender hues fire to colors ranging from white to buff. The light-firing clays are classed as plastic or silty fire clays, and are excellent pottery clays. They vary from the extremely plastic types which have high drying and firing shrinkages and which fire to dense hard bodies at low temperatures, to the extremely silty ones which are weakly plastic, which shrink very little, and which are porous even when fired to high temperatures. A clay suitable for a wide variety of types of ware and firing temperatures can be produced by blending clays.

The clays of the Dakota formation are not only excellent material for producing art pottery, stoneware, decorative tile, terra cotta, and face brick, but, being fire clays, may also be used in making firebricks and other refractory shapes suitable for building or repairing kilns or for making kiln furniture such as props and shelves or saggers.

The Kiowa shale occurs immediately below and the Graneros shale immediately above the Dakota formation. Both of these shales are dark gray and weather into paper-thin flakes. The drying and firing shrinkage of both of these is quite high, and they are extremely plastic. Either can be used for pottery-making but samples of both are difficult to fire without warping or cracking. Furthermore fired colors are not very attractive, being dirty orange or dirty brown depending on the temperature of firing. These shales are also of Cretaceous age.

The belt of outcrop of the Blue Hill shale is normally west of the crops of the Kiowa and Graneros. The Blue Hill is quite similar in appearance and properties to the Kiowa and Graneros shales. The fired color, however, is a dark buff or light brick red. This material can be used with successful results if care is exercised in drying and firing. If its extreme plasticity is reduced by the addition of 25 to 50 percent very fine grog, the Blue Hill shale becomes a very workable material. The grog should be made by firing some of the shale to a very low temperature (cone 015 to 022), crushing it to a powder in a mortar or ball mill, and using only the fine material which passes an 80-mesh or 100-mesh screen. If a coarse grogged body is desired, the grog should be fired to the usual temperature used for the ware.

The only other Cretaceous clay or shale beds found in Kansas occur in the Pierre shale formation which is exposed in scattered areas in the northwestern part of the State. Very little is known about the ceramic value of these materials. Some parts of the Pierre, however, are very similar to the Blue Hill shale.

The bedrock clays and shales which include those of Mississippian, Pennsylvanian, Permian, and Cretaceous age, described in preceding paragraphs, are not exposed over the entire area designated on the clay outcrop map (Fig. 17). On the contrary over a considerable part of the area the material exposed at the surface is geologically much younger deposits of Tertiary or Pleistocene age. Furthermore, over a large part of western and south-central Kansas only Tertiary and Pleistocene deposits are exposed at the surface.

The clay found in these deposits is usually low-grade ceramic material. The variety and the irregularity in occurrence of these clays is too great to permit detailed description. Several usable clays of Pleistocene age and a few of Tertiary age have been tested in the ceramics laboratory of the Geological Survey. The better Pleistocene material consists of reddish glacial clays from the northeastern part of the State. These clays usually fire to a clear red color and take a glaze well. The serious faults of the Pleistocene and Tertiary clays include the presence of impurities such as sand, gravel, and lime nodules, and undesirable working, drying, and firing properties. These clays tend to be both sticky and lean when worked, rather than smooth and plastic. On drying or firing small cracks develop in the ware. The impurities can, in many cases, be eliminated by screening. The stickiness and tendency to crack in some cases may be eliminated by pre-heating to a low temperature, preferably under cone 022. Small amounts of sodium carbonate (soda ash) added to the clay or the tempering water and mixed with the slip will benefit some clays. The amount to use varies with the clay but 2 grams of soda ash to each 1,000 grams of dry clay (0.2 percent) is a good starting point for experimentation. Other clays are benefited by the addition of whiting (calcium carbonate) in amounts up to 5 percent of the dry weight of the clay. It is well to try a small percentage at first, however. Ten grams of whiting per thousand grams of dry clay (1 percent) is sufficient in some cases.

How to Prepare The Crude Raw Clay For Use

Many skilled potters and clay workers know very little about the preliminary preparation of the clay they use. If faced with the problem of preparing their own clay they are inclined to think it a complicated process requiring the knowledge of complex techniques and the use of expensive machinery. If the machinery is available, much time and labor can be saved, but small amounts of material can be prepared for use with almost no equipment.

Clay is usually damp when taken from the earth and one should dry it very thoroughly before he attempts to work it up. Clay which is stored in sacks in a dry place will be fairly dry within a few weeks, but if the drying process needs to be hastened, the clay can be spread out thin on a dry floor, platform, or table.

Crushing or grinding may or may not be required. In the case of massive clays such as those of the Dakota formation and some shales which slake or fall apart in water, grinding helps but is not necessary. Clay and shale that slake very slowly require either grinding or prolonged slaking. Many hard shales will disintegrate in a few months if exposed to the weather. The clay should be spread out thin in shallow boxes or on a clean surface and surrounded by a board "fence" 3 to 6 inches high to prevent the clay from washing away. If the weather is dry, the clay should be soaked with water from time to time. Freezing and thawing will hasten the process of disintegration.

If some crushing or grinding is required and no machinery is available for the work, a large iron mortar and pestle can be used to advantage. One can do the job equally well, however, by spreading the clay on a concrete floor and attacking the chunks of clay with a large mallet or hammer.

Whether the clay is crushed or not, it should next be put into water in a sufficiently large container, such as a tub or stoneware jar. A gallon of water will be required for each 6 to 10 pounds of clay. It is better to use too much water rather than too little. After the clay is added to the water, it should not be stirred or agitated in any way until the lumps of clay have slaked or disintegrated. The longer the clay and water stand the easier it is to work the clay up into a slip.

After the clay has slaked in water, it can be worked into a slip by various means. If it must be done by hand, it is best accomplished by one rolling up his sleeves and going at it with both hands and arms. If this method is employed, lumps can be felt and broken up by the hands. Those who do not wish to get their hands in the clay can do the work with a paddle but with a greater expenditure of effort.

A blunger, or machine for mixing the clay into a slip, is the most helpful mechanical aid with which the clay worker can equip himself. The standard type of blunger consists of an elongated tub in which two paddles slowly rotate in opposite directions. Anyone mechanically inclined can rig up such a device to be run by a motor. Mechanical agitators consisting of a propeller on the end of an elongated electric motor shaft can be purchased from clay equipment manufactures. The agitator can be clamped to a table or to the side of the slip jar or tub. A wooden barrel churn works equally well and costs relatively little. It can be rotated by hand or by power. Some types of washing machines will also do a thorough job of blunging clay. We do much of our laboratory blunging in a large pebble mill with a reduced load of pebbles, and find it works very satisfactorily. If any chemical such as soda ash, whiting, or barium carbonate is to be added to the clay, it should be put in with the dry clay and blunged with it.

After the clay has been blunged or worked up to a smooth slip, it should be screened or sieved. For most work a bronze window screen has a sufficiently fine mesh. For more particular work it is possible to purchase bronze milk-straining screen in large pieces. This screen has about 40 openings to the linear inch. In either case the screen should be tacked to a wooden frame 4 to 6 inches in depth and bound at the edges with thin wood strips such as are used on window screens. Ready-made screens in any mesh size can be purchased from several supply houses. The slip should be fairly fluid for sieving and it should be poured onto the screen from a height of a few inches. If possible one should avoid trying to work the slip through the screen with the hand or other means. To do so tends to blind the screen.

After the slip has been screened, it will probably be too watery for slip-casting, and much water must be removed before it is plastic enough for building, throwing, or modeling. In most cases if the slip is allowed to stand for several hours, clear water will rise to the surface and can be siphoned or dipped off. This method will be adequate to prepare the slip for casting. The removal of the additional water necessary to reduce the clay to the plastic state can be accomplished by various means. The most satisfactory device is a plaster of Paris slab or shallow bowl. The shape is of little importance so long as the plaster is thick enough to absorb a considerable amount of water and large enough to accommodate the amount of slip which must be de-watered. It is often more convenient to use several small drying slabs or bowls rather than one large one. The plaster must, of course, be thoroughly dry before it is used to remove water from the slip. Directions for mixing plaster are given on subsequent pages. The length of time which the slip remains on the plaster surface will have to be judged by the individual worker. The clay should be dry enough to peel from the plaster slab, but wet enough to be workably plastic.

Most clay workers are aware of the necessity of wedging and kneading the clay before attempting to use it, but few do this thoroughly enough. A slightly damp plaster of Paris slab can be used for wedging, but the plaster tends to flake off and mix with the clay. A canvas covered board or a heavy fired clay slab will prove more satisfactory in the long run. The wedging table should also be equipped with a taunt steel wire for cutting the clay while wedging. Clay which is ready for use should be stored in air-tight rust-proof, nonabsorbent containers such as stoneware jars.

METHODS OF FORMING CLAY

It is assumed that the reader is familiar with the various methods of making pottery and other objects from clay. The suggestions offered here are designed to encourage the use of a greater variety of methods and to remind the clay worker of the defects commonly produced by errors in technique.

Pottery-making classes in schools commonly construct the pieces by the use of coils on a hand wheel or by modeling. Very fine work can be done by the former method although considerable care must be exercised in welding the coils together. Air trapped inside the walls of the piece between the poorly joined coils tends to cause cracking or breaking when the ware is fired. This is particularly true if a fat plastic clay is used. Silty or lean clays, on the other hand, are likely to be porous and soft when fired, but poor forming has less effect on them because force applied to the outside of a mass of such clay is transmitted more readily to the interior. Some of the difficulties experienced in using an extremely plastic clay can be eliminated without changing the desirable fired properties. We have accomplished this by firing (or calcining) some of the loose raw clay to cone 017. The buff-firing clay used was soft when fired to this temperature and retained much of its plasticity when mixed with water. It is necessary, however, to grind the clay in water in a ball mill for a few hours to break up lumps. After this treatment the fired or calcined clay will be in the form of a creamy slip and can be mixed with slip made from the raw clay. Various proportions should be tried to obtain the most workable consistency. We found that half calcined and half raw clay worked very satisfactorily. The clay so treated is somewhat less plastic, and the drying shrinkage is greatly reduced. Due to the slight shrinkage the usual drying stains are largely eliminated. The calcined clay slip works very satisfactorily for casting and may be used either alone or mixed with the raw clay slip. The calcined clay is especially useful for casting or pressing flat ware such as plates, saucers, and dishes, because they warp easily on drying. Almost no drying shrinkage occurs if no raw clay is mixed with the slip. The firing shrinkage, however, will be about the same as that of the raw clay.

Although slip-casting of ware does not serve the intended purpose of classes in clay modeling, it is a method which should be employed by anyone producing pottery commercially or for personal use. It is possible to alter cast pieces by centering them on the potter's wheel and applying pressure at the desired points with a tool or the hands in the same manner that coiled pieces are shaped. If a regulation potter's wheel powered by foot-treadle or motor is available, a thick-walled cast piece can be centered and treated as in hand-throwing. This trick eliminates the most difficult portion of the throwing process and produces a good sound piece of uniform texture.

Slip-casting also permits the use of novel means of decoration. Designs can be painted on the inside of a partially damp plaster mold by the use of engobes, or colored clay slips. Naturally colored clays, differing from that of the body, or artificially colored engobes may be used. After the design is painted on the mold, the piece is cast in the usual manner. When removed from the mold the design is found to be inlayed in color on the outside of the ware. The plaster molds must, of course, be of a type which will permit easy access to the inside. If desired the colored engobes may be painted on the outside of the leather-hard ware or even the fired piece, but the design will be slightly raised.

Some of the coloring oxides and the percentages required for various colors are listed in Table 27.

TABLE 27.—*Colors which can be produced by the addition of metallic oxides or salts to clay*

Color produced	Oxide or Salt	Grams of oxide to 100 grams of base clay
Added to light-firing clay		
Light blue	Cobalt carbonate	1.5
Dark blue	Cobalt carbonate	7.0
Green	Chromium oxide	11.0
Black	Red iron oxide	5.0
	Nickel oxide	3.0
	Black iron oxide	7.0
	Manganese carbonate	7.0
	Cobalt oxide	4.0
Added to red-firing clay		
Brown	Chromium oxide	1.0
	Rutile	2.0
	Manganese carbonate	2.0
Black	Nickel oxide	3.0
	Black iron oxide	7.0
	Manganese carbonate	7.0
	Cobalt oxide	4.0

THE PREPARATION AND USE OF PLASTER OF PARIS

Plaster of Paris suitable for mold making and slip casting comes in several grades. For ordinary work the molding plaster sold by lumber dealers is quite satisfactory. Some of the major gypsum processing companies manufacture a line of pottery plasters adapted to specific ceramic uses. Detailed information can be obtained by writing to the central offices of those companies.

Plaster of Paris is prepared for use by slowly adding the dry plaster to the water by shaking the plaster through a course sieve, or for less careful work, by sifting it through the fingers. A proportion of 2¾ pounds of plaster to 1 quart of water is recommended. After adding the plaster to the water, it should be allowed to soak without stirring for 2 to 4 minutes. It should then be stirred or mixed with the hands, a paddle, or a motor-driven propeller-type agitator for an additional 2 to 3 minutes. In some cases longer periods of time are required for both soaking and mixing.

When the mixture starts to thicken in consistency and becomes perceptably warmer, it is time to pour the plaster into the molds. This must be done rather rapidly, because ordinary plaster sets rapidly. The plaster should be poured smoothly, with a minimum of agitation to prevent the inclusion of air bubbles. Jarring the plaster container before pouring and jarring the mold after pouring helps to eliminate air bubbles. Plaster should always be handled in clean containers to prevent an unduly rapid set.

KILNS SUITABLE FOR SMALL-SCALE PRODUTION

Most ceramic craftsmen and operators of small art potteries are not ceramic engineers, and usually are not acquainted with the methods of constructing kilns. It is advisable for such persons to purchase ready-made periodic muffle kilns. We have found the fire-tube type of gas-fired muffle kiln very easy to operate and also quite durable. Ordinarily kilns of this type are designed for firing to temperatures up to cone 4. If higher firing temperatures are required, kilns with special linings can be purchased.

Electric kilns are easy to operate and give good results. However, both first cost and cost of operation of electric kilns are greater than for gas or oil-fired kilns. The newer types of electric kilns, having silicon carbide rather than metallic heating elements, are especially satisfactory. Such kilns are designed for maximum operation temperatures ranging from 2,300 degress F. to 2,700 degrees F. (cone 9 to cone 18). If used at the usual temperatures of cone 06-04, the kilns should give long and satisfactory service.

Those who are acquainted with the construction of kilns, or who can obtain some one to do the work, can save money by installing a small down-draft kiln constructed of fire brick. The chief objection to the down-draft kiln is that the ware is exposed to the gases of combustion. Saggers must be used if the ware is at all sensitive to such conditions.

GLAZES

Many books have been written on the subject of glazes. The material given here may be of some assistance to those who wish to mix their own glazes and experiment a little.

Essentially a glaze is glass, or a mixture of melted silicates. The most important ingredient of a glaze is silica, known to the ceramist as "flint." Natural silicates such as kaolin, plastic clay, feldspar, and nepheline syenite are also used as well as such prepared silicates as powdered window glass, frits, lead silicates, and water glass.

The flint and clay are not fusible at ordinary temperatures, but with the addition of sufficient amounts of fluxes such as lead carbonate, lead oxides, lithium carbonate, soda ash, borax, and colemanite, the mixtures melt into a glass or glaze within the low temperature range the potter is accustomed to using—that is, cone 010 to cone 1. At higher temperatures feldspar, nepheline syenite, whiting, zinc oxide, iron oxide, volcanic ash, and other materials act as fluxes. Normally, one or more high temperature fluxes, such as feldspar or volcanic ash, are used in low temperature glazes.

With the above facts in mind it is possible to produce usable glazes by experimenting with various proportions of flint-plus-clay as the base with one or more of the fluxes mentioned above.

One of the simplest glazes known is the often-mentioned 1-2-3 glaze consisting of one part clay, two parts flint, and three parts lead carbonate (white lead). These are parts by weight as are all the glaze formulas given below. (It is well to remember that lead compounds are poisonous, and that reasonable care must be used in keeping the dust, glaze, or glaze mist from the mouth and nose.) The 1-2-3 glaze matures at about cone 010 and can be used at temperatures up to cone 05. It is a glossy, transparent glaze.

Four other easily prepared transparent glazes which mature at cone 06 or lower are given below. The ingredients are given in percentages.

Raw Materials	No. 1	No. 2	No. 3	No. 4
Lead carbonate (white lead)	50	46	58	58
Whiting (calcium carbonate)	8	4		
Feldspar	25	15	20	
Kaolin (china clay)	5	5	7	7
Flint (silica flour)	12	20	15	10
Borax		8		
Barium carbonate		2		
Volcanic ash				25
	100	100	100	100

We have found that very attractive results could be obtained by the use of a semi-matt or vellum glaze containing titanium oxide. Below is given the glaze formula both with the conventional ingredients and with volcanic ash (Plummer, 1939). Amounts are given as percentages.

Raw materials	Glaze No. BM-O	Glaze No. BM-1
Volcanic ash	23.8	
Lead carbonate	45.3	51.4
Whiting	6.4	6.2
Zinc oxide	6.8	6.2
Kaolin (Florida, preferred)	7.0	14.5
Flint	0.5	12.4
Tin oxide	4.5	4.1
Titanium dioxide	5.7	5.2
	100.0	100.0

Glazes BM-0 and BM-1 usually are fired at temperatures ranging from cone 07 to cone 05. Slight differences in temperature have a marked effect on the color and texture of the glazes. Glaze BM-0 fires to a cream color and glaze BM-1 to an ivory. The glazes should be applied evenly and in a rather thick coat.

Interesting varigated colors are obtained by adding coloring oxides or salts to the above base glazes. Percentages of coloring ingredients we have used with the resulting colors are given below.

Coloring carbonate or salt	Parts by weight added to 100 parts of base glaze BM-0 or BM-1	Color resulting in in glaze BM-0	Coloring resulting in glaze BM-1
Cobalt carbonate	0.5	gray tan	gray blue
Sodium uranate	2.38	yellow brown	yellow brown
Red iron	2.38	yellow brown	yellow brown
Sodium uranate	2.26	yellow cream	yellow cream
Copper carbonate	2.26	yellow green	yellow green

The addition of varying amounts of chrome-tin-pink stain will produce colors varying from rose to dark maroon in the above base glazes.

Sheldon Carey of the University of Kansas Department of Design has succeeded in using as much as 70 percent volcanic ash in glazes which mature between cone 05 and cone 04, but which can be fired as high as cone 9 (Carey and Fosdick, 1946). To 70 percent volcanic ash is added either 30 percent borax or 30 percent colemanite. The borax glaze is of course more fusible than the colemanite one. The glaze can be made white and semi-opaque by the addition of 5 percent tin oxide.

Glazes maturing at higher temperatures usually contain fewer ingredients, and on the whole produce better results than the lower temperature glazes. Below are given three higher temperature glazes (Ceramic Industry, Ceramic Materials Issue, January, 1946, p. 154). Ingredients are given as percentage.

Raw materials	Cone 2	Cone 5	Cone 6-8
Feldspar	31.9	30.9	58.8
Whiting	8.6	5.5	10.5
Zinc oxide	2.3	2.2	11.2
Red lead	26.2		
Lead bisilicate		47.6	
China clay (kaolin)	5.5	7.1	
Ball clay	5.7		9.0
Flint	19.8	6.7	10.5
	100.0	100.0	100.0

The above glazes can be applied in a thinner coat than the usual raw low temperature glaze. The glazes can be made opaque white by adding tin oxide, and colored by the usual coloring oxides.

There are clays which are sufficiently fusible to be used as glazes. The well-known Albany slip is an example. We have found that some of the shale samples taken from the Ninnescah shale formation and Wellington shale formation of Permian age are suitable for the so-called "slip glazes." One in particular which we sampled on the creek bank west of Johnstown station about 7 miles north and one-half mile west of McPherson proved to be an excellent slip glaze. At cone 8 it has a semi-gloss texture and a pinkish-tan color. At cone 11 it is a glossy light golden-brown glaze. The addition of 25 percent volcanic ash lowers the maturing temperature about two cones. The addition of more fusible materials such as borax, colemanite, lead oxide, or lithium carbonate would make it possible to use this slip glaze clay at much lower temperatures. Due to the fact that the fired color is relatively light for this type of glaze it is possible to alter the color by adding iron oxide, chromium oxide, cobalt oxide, and titanium oxide, or any desired combination of these.

The preparation of glazes for use can be a relatively simple matter. If pulverized raw materials are used it is necessary only to weigh the dry ingredients carefully, dry mix them with a spoon, add water to form a creamy slip or suspension, and put the slip through a screen having eighty meshes to the lineal inch. The glaze suspension or slip should be stirred thoroughly each time before using.

We have found that the most fool-proof method of applying glazes is by spraying. If nothing else is available an ordinary fly spray gun will do the job well. Glazes can also be applied by brushing or dipping. It is difficult however, to obtain an even coat of glaze by brushing, and dipping requires some experience.

Nothing has been said before about the use of frits or fritted glazes. It is assumed that the person who has enough equipment to prepare frits is also somewhat experienced in the field. If it is possible, the use of frits is recommended because better results can be obtained with fritted glazes. Frits of standard compositions can be purchased, or frits can be made up according to specifications. Furthermore, lead compounds can be made insoluble and harmless, and such useful leadless compounds as soda ash and borax can be incorporated in a frit. They are not usable except in small amounts in a raw glaze, however.

REFERENCES

AMERICAN SOCIETY FOR TESTING MATERIALS, *1944*, A.S.T.M. Standards, part II, Nonmetallic materials—constructional, pp. 1-1649, Baltimore, Md.

ANONYMOUS, *1944*, Central Kansas clay deposits: U. S. Bur. Mines, War Minerals Rept. 297, pp. 1-5.

BERKELHAMER, L. H., *1944*, An apparatus for differential thermal analysis: U. S. Bur. Mines, Rept. Investigations 3762, pp. 1-17, figs. 1-9.

CAREY, SHELDON, and FOSDICK, MARIAN, *1946*, Glaze material. Mimeographed class material.

CERAMIC INDUSTRY, *1946*, Ceramic materials issue, January, pp. 1-168, Industrial Publications, Inc., Chicago, Ill.

CHUTE, A. H. *1939*, Marketing burned clay products, pp. 1-374, charts 1-12, maps 1-9, Ohio State Univ. Press, Columbus, Ohio.

COX, P. E., *1938*, The use of Iowa clays in small-scale production of ceramic art: Iowa Engr. Exp. Sta., Bull. 133, pp. 1-48, figs. 1-23.

FAIRCHILD, C. O., and PETERS, M. F., *1926*, Pyrometric cone-temperature-time relation table: Jour. Am. Ceramic Soc., vol. 9, pp. 701-743.

FRYE, J. C., LEONARD, A. B. and HIBBARD, C. W., *1943*, Westward extension of the Kansas "Equus beds": Jour. Geology, vol. 51, no. 1, pp. 33-47, figs. 1-3.

GRAHAM, R. P., and SULLIVAN, J. D. *1939*, Workability of clays: Jour. Am. Ceramic Soc., vol. 22, no. 5, pp. 152-156, figs. 1-9.

Grim, R. E., *1939*, Relation of the composition to the properties of clays: Jour-Am. Ceramic Soc., vol. 22, no. 5, pp. 141-151, figs. 1-4.

———, *1939a*, Properties of clay: Illinois Geol. Survey, Circ. No. 49, pp. 466-495, figs. 1-4.

———, *1941*, Petrographic and ceramic properties of Pennsylvanian shales of Illinois: Jour. Am. Ceramic Soc., vol. 24, no. 1, pp. 23-28, figs. 1-10.

———, *1942*, Modern concepts of clay materials: Jour. Geology, vol. 50, no. 1 pp. 225-275, figs. 1-12.

Grim, R. E., and Bradley, W. F., *1940*, Investigation of the effect of heat on the clay minerals illite and montmorillonite: Jour. Am. Ceramic Soc., vol. 23, pp. 242-248, figs. 1-5.

Grim, R. E., and Bray, R. H., *1936*, The mineral constitution of various ceramic clays: Jour. Am. Ceramic Soc., vol. 19, pp. 307-315.

Grim, R. E., Bray, R. H., and Bradley, W. F., *1937*, The mica in argillaceous sediments: Am. Mineralogist, vol. 22, pp. 813-829.

Grim, R. E., and Cuthbert, F. L., *1945*, Some clay-water properties of certain clay minerals: Jour. Am. Ceramic Soc., vol. 28, no. 3, pp. 90-95, figs. 1-6.

Grim, R. E., and Rowland, R. A., *1942*, Differential thermal analysis of clay minerals and other hydrous materials: Am. Mineralogist, vol. 27, no. 11, pp. 746-761, figs. 1-7, no. 12, pp. 801-818, figs. 8-14.

———, *1944*, Differential thermal analysis of clays and shales, a control and prospecting method: Jour. Am. Ceramic Soc., vol. 27, no. 3, pp. 65-76, figs. 1-17.

Harman, E. G., and Parmelee, C. W., *1942*, Testing and classification of ball clays: thermal history: Bull. Am. Ceramic Soc., vol. 21, no. 11, pp. 283-286, figs. 1-11.

Henry, E. C., *1942*, Plasticity and workability of clays: Bull. Am. Ceramic Soc., pp. 269-271.

Hillebrand, W. F., *1919*, The analysis of silicate and carbonate rocks: U. S. Geol. Survey, Bull. 700, pp. 1-285, figs. 1-23.

Hillebrand, W. F., and Lundell, G. E. F., *1946*, Applied inorganic analysis, 9th prtg., pp. 1-929, figs. 1-40, John Wiley & Sons, New York.

Hills, F. G., *1937*, The technical analysis of ores and metallurgical products, pp. 1-197, New York Chemical Publishing Co. of New York, Inc., New York.

Hodgeman, C. D., *1935*, Handbook of chemistry and physics, pp. 1-1951, Chemical Rubber Publishing Co., Cleveland, Ohio.

Humbert, R. P., *1942*, Particle shape and the behavior of clay as revealed by the electron microscope: Bull. Am. Ceramic Soc., vol. 21, no. 11, pp. 260-263, pls. 1-2.

Jewett, J. M., and Schoewe, W. H., *1942*, Kansas mineral resources for wartime industries: Kansas Geol. Survey, Bull. 41, pt. 3, pp. 69-180, figs. 1-13.

Kolthoff, I. M., and Sandell, E. B., *1946*, Textbook of quantitative inorganic analysis, rev. ed., pp. 1-794, figs. 1-131, The MacMillan Co., New York.

Kinney, E. D., *1942*, Kansas bentonite: its properties and utilization; Kansas Geol. Survey, Bull. 41, pt. 10, pp. 349-376, fig. 1, pls. 1-2.

Kruger, E. V., *1940*, The outlook for Kansas clay products industries: Univ. of Kansas, Industrial Research Ser., no. 1, pp. 1-42.

Landes, K. K., and Keroher, R. P., *1942*, Mineral resources of Phillips County: Kansas Geol. Survey, Bull. 41, pt. 8, pp. 277-312, figs. 1-5, pls. 1-4.

McNamara, E. P., *1938*, Ceramics, vol. 2, pp. 1-359, figs. 1-148, Pennsylvania State College, State College, Pa.

Newcomb, Rexford, Jr., *1947*, Ceramic whitewares, pp. 1-313, figs. 1-1 to 13-3, Pitman Publishing Corp., New York.

Pask, J. A., and **Davies**, **Ben**, *1943*, Thermal analysis of clay minerals and acid extraction of alumina from clays: U. S. Bur. Mines, Rept. of Investigations 3737, pp. 1-28, figs. 1-4.

Plummer, **Norman**, *1939*, Ceramic uses of volcanic ash: Bull. Am. Ceramic Soc., vol. 18, no. 1, pp. 8-11.

Plummer, **Norman**, and **Romary**, J. F., *1942*, Stratigraphy of the pre-Greenhorn Cretaceous beds of Kansas: Kansas Geol. Survey, Bull. 41, pt. 9, pp. 313-348, figs. 1-4, pls. 1-2.

Ries, **Heinrich**, *1925*, Economic geology, 5th ed., pp. 1-843, figs. 1-291, pls. 1-75, John Wiley & Sons, New York.

———, *1927*, Clays, their occurrence, properties, and uses, 3d ed., pp. 1-613, figs. 1-173, John Wiley & Sons, New York.

Ries, **Heinrich**, *et al.*, *1939*, Report of Committee on Geological Surveys, clay definitions: Bull. Am. Ceramic Soc., vol. 18, no. 6, pp. 213-215.

———, *1945*, Report of Committee on Geological Surveys, distribution of clays in the United States: Bull. Am. Ceramic Soc., vol. 24, no. 7, pp. 234-245.

Scott, W. W., *1939*, Standard methods of chemical analysis, vol. 1, 5th ed., pp. 1-1234, figs. 1-132, D. Van Nostrand Co., Inc., New York.

Seger, H. A., *1902*, The collected writing of Hermann August Seger, vol. 1, pp. 1-551, American Ceramic Society and Chemical Publishing Co., Easton, Pa.

Shaw, B. T., *1942*, Nature of colloidal clay as revealed by the electron microscope, Jour. Physical Chemistry, vol. 46, pp. 1032-1043.

Smothers, W. J., and **Herold**, P. G., *1944*, A study of the flow properties of concentrated clay-water mixtures: Missouri School of Mines, Tech. Ser., vol. 15, no. 3, pp. 1-102.

Speil, **Sidney**, *1944*, Applications of thermal analysis to clays and aluminous minerals: U. S. Bur. Mines, Rept. Investigations 3762, pp. 1-17, figs. 1-10.

Speil, **Sidney**, **Berkelhamer**, L. H., **Pask**, J. A., and **Davies**, **Ben**, *1945*, Differential thermal analysis: its application to clays and other aluminous minerals: U. S. Bur. Mines, Tech. Paper 664, pp. 1-81.

Sullivan, J. D., *1938*, Uses, trends, and developments of refractories in the United States: Am. Refractories Institute, Tech. Bull. 66, pp. 1-6.

Teetor, **Paul**, *1914*, The clays of eastern Kansas: Trans. Am. Ceramic Soc., vol. 16, p. 120.

Teetor, **Paul**, *1921*, Clay and shale resources in the vicinity of Arkansas City, Kansas: Kansas Geol. Survey, Bull. 8, pp. 38-47, pls. 12-13.

Washington, H. S., *1930*, The chemical analysis of rocks, 4th ed., pp. 1-296, John Wiley & Sons, Inc., New York.

Watts, A. S., *et al.*, *1928*, Standard methods for sampling ceramic materials, preparation of clay trials, standard test methods, tentative test methods, and test apparatus: Jour. Am Ceramic Soc., vol. 11, no. 6, pp. 442-467, 490-534.

Weeks, M. E., *1942*, A laboratory manual of quantitative analysis, pp. 1-65, Edwards Bros., Inc., Ann Arbor, Mich.

Whitlach, G. I., *1940*, The clays of west Tennessee: Tennessee Div. of Geology, Bull. 49, pp. 1-328, figs. 1-38, pls. 1-10.

Whittemore, J. W. *1942*, Water of plasticity: Bull. Am. Ceramic Soc., vol. 21, no. 11, pp. 268-269.

Wing, M. E., *1930*, The geology of Cloud and Republic Counties, Kansas: Kansas Geol. Survey, Bull. 15, pp. 1-51, figs. 1-2, pls. 1-18.

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LOCATIONS AT WHICH CLAY SAMPLES WERE COLLECTED

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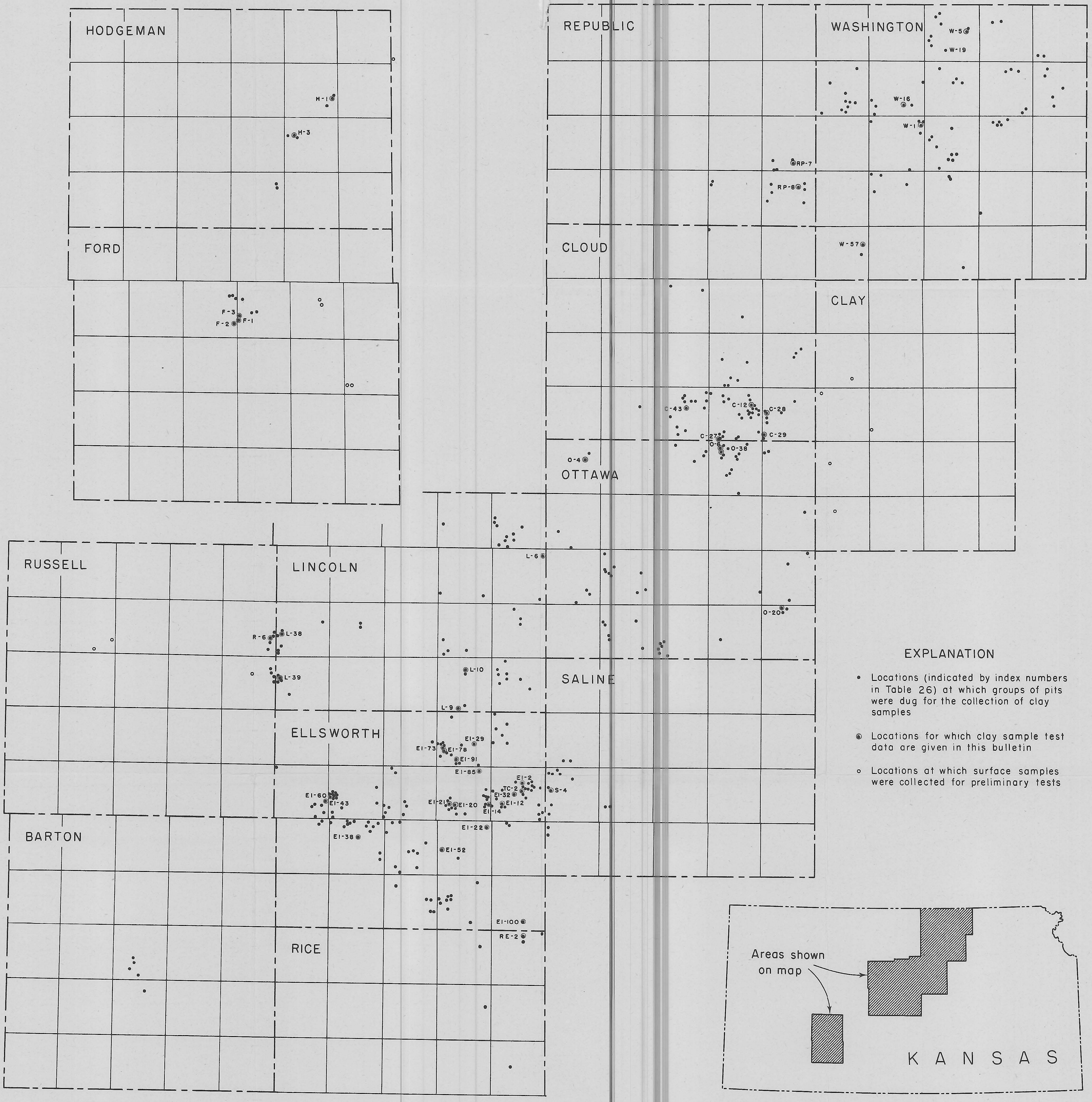

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Bulletin 67, Plate 2

WATER OF PLASTICITY, SHRINKAGE WATER, AND PORE WATER IN KANSAS CLAY SAMPLES

By Norman Plummer and John F. Romary

1947