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PRELIMINARY REPORT ON THE CLAYS AND SHALES OF MINNESOTA

BY

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AND

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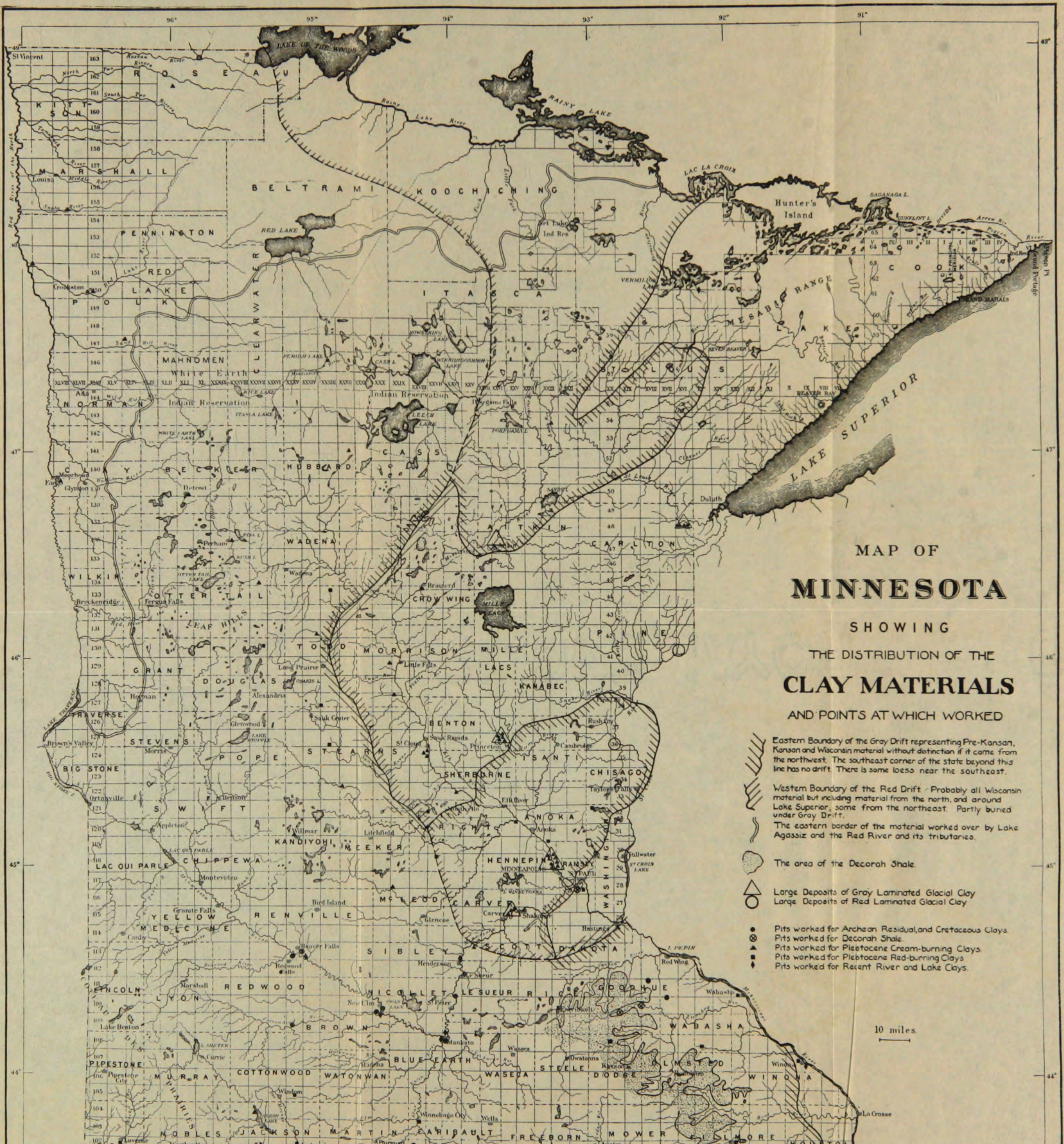
ILLUSTRATIONS


MAP OF
MINNESOTA
SHOWING
THE DISTRIBUTION OF THE
CLAY MATERIALS
AND POINTS AT WHICH WORKED
Eastern Boundary of the Gray Drift representing Pre-Kansan, Kansan and Wisconsin material without distinction if it came from the northwest. The southeast corner of the state beyond this line has no drift. There is some loess near the southeast.
Western Boundary of the Red Drift. Probably all Wisconsin material but including material from the north, and around Lake Superior, some from the northeast. Partly buried under Gray Drift.
The eastern border of the material worked over by Lake Agassiz and the Red River and its tributaries.
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Pits worked for Pleistocene Cream-burning Clays.
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Pits worked for Recent River and Lake Clays.
10 miles.
LAKE OF THE WOODS
RAINY LAKE
RED LAKE
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MESABI RANGE
Hunter's Island
Duluth

THE CLAYS AND SHALES OF MINNESOTA

OUTLINE OF PAPER

This paper discusses briefly the distribution, origin, properties, classification, and adaptability of the clays and shales of Minnesota. An attempt has been made to test all the more important deposits with sufficient care and exactness to determine the purposes for which they may be used. To render the data more readily accessible the following outline is given.

Detailed results of tests are stated in Chapter VII. The technical terms used in the discussion are briefly explained in the sections on Technology and Physical Properties, Chapters II and IV.

In Chapter VI certain areas are recommended for prospecting and development. Fire clays are to be found in the central to southwestern parts of the State, and semi-refractory clays are somewhat more widely distributed. These should be sought by drilling.

The general character of each geologic formation and the character of the clay products made from them by various methods of manufacture are given in the latter part of Chapter V. The map, Plate I, shows the main features of the distribution of clays.

As stated in Chapter V, the gray drift is widely distributed and is one of the most important sources of clay in the State. After the limestone pebbles have been removed, it can be made into excellent drain tile, for which there will be an increasing market as the swamp lands of the State are drained. The expense of the process of removing the limestone is not so great as to be prohibitive. Some details of the process are given in Chapter IV.

It is believed that an excellent fancy brick may be made from the upper Huronian slates at Carlton and vicinity (page 79) if a small percentage of red drift is added.

Deposits suitable for common brick are abundant and widely distributed. The red drift, capable of making vitrified brick, is distributed in many accessible localities in the eastern part of the State. The red laminated clays of the eastern counties make good red brick and may be used as a slip glaze for semi-refractory ware.

CHAPTER I

INTRODUCTION

OBJECTS AND SCOPE OF PAPER

This bulletin is a preliminary paper outlining the principal results of an investigation of the clay resources of Minnesota, which was carried on during the summer of 1912. A more comprehensive report is now in progress and will be issued later. In general, the object of the work has been to assist in the development of the clay resources of Minnesota. The broader problems of ceramics are treated only incidentally. Some of the important scientific conclusions of the American Ceramic Society, of the Bureau of Standards, and of surveys of other states are briefly reviewed here in order that they may be more readily available to those whose chief interests are technical and commercial. A more extended treatment of the scientific results of the investigation will appear later.

Specifically, the object has been (1) to investigate the sources of clay for every town of 1,000 or more inhabitants, and for each county of the State; (2) to ascertain the extent of several deposits now developed at only a few points; (3) to find new deposits; and (4) to determine the qualities of these deposits and of certain mixtures, to ascertain whether it is possible to produce some refractory wares, pottery, paving brick, and certain other high-grade products that are now carried considerable distances to the Minnesota markets.

ACKNOWLEDGMENTS

The work has been done in coöperation with the United States Geological Survey, and it is planned to issue the final bulletin on the coöperative basis. Acknowledgments are given to Messrs. Oliver Bowles, George L. Harrington, and F. M. Handy, who assisted in the work, and to Messrs. Frank Leverett, F. W. Sardeson, and A. W. Johnston for contributions of certain geological data; to Mr. Jefferson Middleton, of the United States Geological Survey, for lists of producers; to the United States Bureau of Standards for tests; to the Minnesota School of Mines Experiment Station for firing tests; to the Experimental Engineering Department of the University for tests of the products; to J. G. Houghton, Minneapolis Inspector of Buildings, for tests of brick and tile; and to Dr. C. P. Berkey for unpublished data collected in 1902. The work in the field has been greatly facilitated by the friendly coöperation of Commercial Clubs and other organizations of similar purpose, and by many indi-

viduals. Sincere thanks are due Mr. M. C. Madsen, of Hutchinson, Messrs. E. S. Hoyt and J. H. Rich, of Red Wing, Dr. O. C. Strickler, of New Ulm, and many others.

DEFINITIONS

Clay is defined in two ways: (1) an earthy aggregate consisting essentially of the mineral kaolinite, or some nearly related hydrous aluminum silicate; (2) any earthy mass which becomes plastic when wet. The mineral kaolinite has the composition $H_4Al_2Si_2O_9$; its specific gravity is 2.6; it is monoclinic in crystal form; it is white, unless impure. Halloysite, pyrophyllite, cimolite, bauxite, and opal are species frequently associated with kaolinite. Shale is a term frequently employed in the same sense as clay, but as a rule it is applied to hard, laminated clays, generally of marine origin.

ORIGIN OF CLAY

All, or nearly all, of the clay minerals are secondary in origin, and are derived by the hydrous alteration of other silicate minerals, components of the so-called crystalline rocks. The following list shows approximately the chemical composition of the most common rock-making silicates.

Orthoclase = potassium aluminum silicate
Albite = sodium aluminum silicate
Anorthite = calcium aluminum silicate
Muscovite = hydrous potassium aluminum silicate
Biotite = iron magnesian aluminum silicate
Hornblende = a complex silicate containing as a rule iron, magnesium, calcium, and aluminum
Augite = ditto.

By various natural reactions some or all of these minerals are commonly altered to kaolinite or the related clay materials. The particular circumstances under which natural reactions produce kaolinite from other minerals have been the subject of considerable discussion, especially as regards those reactions which have produced large bodies of relatively pure kaolinite. It has been stated that the action of hydrofluoric acid may form kaolinite from orthoclase at great depths in the earth, but it seems probable that only a very small portion of the kaolinite known has been so formed. The slower, but more general, process of weathering at the surface is of much greater importance. Weathering is usually, but not invariably, accompanied by processes of erosion and sedimentation.

ROCK WEATHERING

Weathering includes both chemical effects, known as decomposition, and mechanical effects known as disintegration, which are usually simultaneous and closely related. Many rock minerals are partially soluble in circulating water, and, as a part of the mineral is removed, water may combine with the residue, producing hydrous minerals. (See Fig. 1.) These are usually softer and more loosely bound together than the original minerals, and hence are more easily affected by mechanical processes. The mechanical processes are erosion by streams carrying sediments, erosion by wind-blown sand, by ice, by the pounding of waves, by the unequal expansion resulting from alternation of heat and cold, etc. All the mechanical processes result in breaking up rocks into finer particles than the original, so that circulating water has easier access to bring about decomposition.

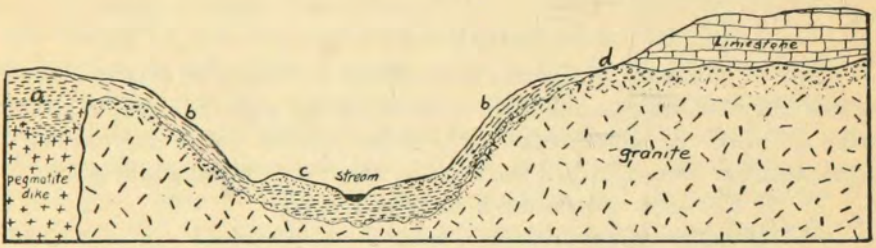


FIGURE I. ILLUSTRATING THE ORIGIN OF CLAYS.
a. RESIDUAL CLAY, KAOLIN. *b.* COLLUVIAL CLAY.
c. ALLUVIAL CLAY. *d.* DECOMPOSED GRANITE, PARTIALLY ALTERED TO CLAY.

The solvent action of circulating water on minerals is greatly increased by the presence of dissolved gases and salts. Carbonic acid and oxygen are especially effective, and the organic products of bacteria and animal and vegetable life in general are noteworthy.

The result of weathering on rocks depends largely upon the relative amounts of decomposition and disintegration. A powder formed chiefly by the grinding up of crystalline rocks must naturally have properties radically different from one formed by the chemical solution of part of the rock. One is spoken of as "rock flour," and the other as "rock rot." Glacial erosion, for example, is mostly mechanical and yields rock flour. The finest particles which result from weathering in either case usually constitute a clay, and, by the nature of the process of formation, such clay is likely to be mixed with numerous remnants of the original minerals from which it was formed. An elaborate discussion of weathering, with a bibliography, is to be found in Vol. XIII of the Transactions of the American Ceramic Society.

EROSION AND SEDIMENTATION

Most important are the processes of erosion and sedimentation. Clay particles formed by weathering are finer grained than particles of the sand and gravel, and, when washed by water, a separation is often accomplished. The carrying power of running water varies greatly with its velocity. Thus a stream which under normal conditions would gather up and carry particles of clay, might not flow fast enough to carry grains of sand except at times of great floods. This separation is of great importance in the accumulation of large bodies of clay free from sand. Some streams flow fast enough at all seasons to carry both the sand and clay, yet a later sorting process may occur and yield beds of clay free from sand, for, where such streams reach a lake or the ocean, the currents are checked only partially at first, and the coarser sand is deposited near shore, while the clay accumulates farther out. Similarly, shore currents and waves may separate sand from clay and the latter may be deposited farther from the shore.

ALTERATION

After the formation of a clay, geologic processes may modify it in many ways. Circulating waters may leach from it certain soluble elements (see Fig. 2) or, on the other hand, may deposit mineral matter as cement or as concretionary masses. An increase of temperature may dehydrate it and destroy the minerals present. By these and similar processes a clay deposit may be changed.

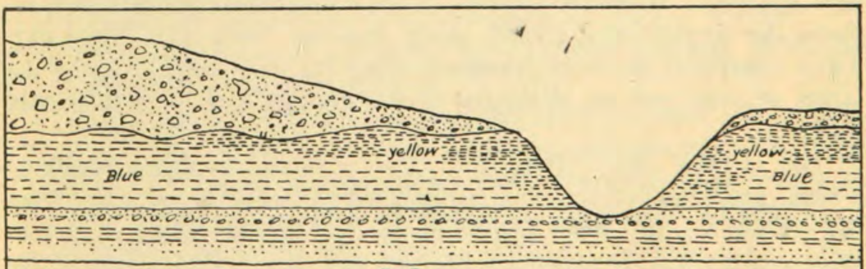


Fig. 2
Sketch showing influence of thickness of drift on depth of weathering of clay

GEOLOGIC TYPES OF DEPOSITS

1. RESIDUAL DEPOSITS

The weathering and superficial decay of granitic igneous rocks sometimes produces a sheetlike mantle of clay of great lateral extent and as much as 100 feet in thickness. As a rule such deposits follow the irregularities of the original rock surface, their base depending more or less closely upon the water level and the topography at the time they were formed. Another less common form of residual clay results from the alteration of igneous dikes. The impurities depend largely upon the completeness of alteration. Such residual clays, when white-burning, are called kaolins. Kaolin—a rock—should be carefully distinguished from kaolinite—a mineral. Ries[1] has summarized the theories of the origin of kaolins.

2. TRANSPORTED DEPOSITS

(a) *Marine deposits.*—Sedimentation in the deep sea produces this type of clay, and the circumstances of its formation tend toward great lateral extent as compared with thickness. At its edge the clay body may show a gradation into limestone or sandstone. Vertically, also, there may be such gradations, and, in addition, there is likely to be an alternation with these rocks, which are consequently the chief impurities to be expected. The Decorah shale is a good illustration in Minnesota. Subsequent deposition of concretions may add to the impurities. Under favorable conditions impurities may be leached out. If later marine formations cover the clay deeply, the pressure they exert may consolidate the clays into shales. Where the shales are exposed by erosion, they weather again into soft clays.

(b) *Lake clays.*—These originate by much the same processes as the marine clays, but the clay bodies are generally less extensive.

(c) *Alluvial clays.*—Rivers which carry large amounts of fine sediment always vary in the rapidity of their currents in different parts of their channels. Wherever an eddy or other irregularity occurs which reduces the current very greatly, sandy clays are likely to be deposited. These conditions are most prominent along the wide flood plains of the larger streams, and are illustrated by the deposits along the Minnesota River.

(d) *Glacial clays.*—The glacial drift, as carried by the ice, has only a small proportion of clay, but, as modified by the action of water from the melting ice, this small proportion of clay may be concentrated into valuable deposits. It sometimes happens that the abrasive action of the ice grinds up a considerable mass of rock to a fine powder without any extensive decomposition. This so-called rock flour has many of the properties of clay and has been used as a brick material, but where used in Minnesota it is evident that decomposition has turned some of the minerals into kaolinite. Many lake and alluvial clays of glacial origin resemble the lake and alluvial clays not connected with glacial action, but they are of sufficient importance and extent in Minnesota to warrant separate treatment.

[1]Ries, H., The origin of kaolins: Trans. Am. Cer. Soc., Vol. 13, p. 73.

3. SLATES

Great accumulations of clay in the older formations of Minnesota have been so deeply buried and so intensely altered as to change their mineral composition and physical properties. These are classed as metamorphic slates.

RELATION OF TYPES

These various types of clay as described from a geologic standpoint are not always easily distinguished in the hand specimen or even in the field. Even the fundamental genetic distinctions between residual and transported clays are often difficult to apply, and there are prominent gradations between the several classes. The type of origin, as here outlined, bears no traceable relation to the applicability of the clay as ceramic material. One marine shale may be good fire clay and another, a fusible slip clay, without any possible distinction in the mode of formation.

CHEMISTRY OF CLAY

The following elements and oxides are usually reported as chemical constituents of clay.

Silica, SiO_2, is an essential part of the chief mineral, kaolinite, and is present in several associated minerals. It exists abundantly uncombined in the sand of sandy clays.

Alumina, Al_2O_3, is a second essential oxide of kaolinite, present also in a few other minerals.

Combined water, H_2O, is a third essential oxide of kaolinite.

Moisture is usually present in clays in large amounts, although this is not always apparent to the eye.

Iron minerals.—The oxides and sulphides are common constituents of clay, but, as they are entirely absent from some clays and seriously affect the fusibility and general behavior of the clay that contains them, they are classed as impurities, though not necessarily undesirable. Iron oxide gives red bricks their color.

Calcium is very common in clays as the carbonate and is often present as the sulphate. It has a tendency to counteract the color of iron oxide when clay is burned. Its effect on the manner of fusion of a clay is frequently disastrous, as the bricks melt suddenly and at low temperatures. Especially bad for the clay are lumps of limestone, calcium carbonate, which burn to lime and later slake and swell with such force as to burst the brick. For these and other injurious effects, calcium is classed as an impurity.

Magnesia is similar to lime, but not as injurious.

Alkalies, soda and potash, are found in most clays and are not undesirable, except for fire clays, where they lower the point of fusion.

Miscellaneous elements include sulphur, and the oxides of titanium, copper, manganese, and phosphorus, and various carbon compounds.

STATE OF MINERAL COMBINATION

The elements mentioned above behave differently depending on their state of combination, i. e., on the minerals which are present in the clay. The minerals observed in the clays of this State are: kaolinite and related aluminum silicates; pyrite,' bauxite, quartz, hematite, limonite, calcite, dolomite, siderite, hornblende, micas, gypsum, feldspars, chlorite, rutile, and glauconite. Other minerals often found and likely to be present are the oxides of manganese, alum, epsomite, zeolites, etc.

No systematic classification has been devised to indicate the minerals or elements present, but the terms calcareous or ferruginous clays may be used to indicate the presence of lime or iron.

Rational analyses are attempts to determine the proportion of the common minerals present in clay, but are valuable only for those clays that contain few minerals. No method is devised to separate and estimate such a list of minerals as occur in common clay.

Chemical analyses are of relatively small importance in judging the value of clay, for in general the results of simple, physical tests are more applicable to technical problems.

CHAPTER II

THE PHYSICAL PROPERTIES OF CLAYS

With all the different materials which make up clays, mixed in an infinite variety of proportions, it is to be expected that there will be a great range in the behavior and the applicability of clays. Some of the qualities of these mixtures are extremely important and are the very foundation of most of their uses. They may be tabulated as follows:

1. Plasticity when wet.
2. Shrinkage when drying.
3. Tensile strength when dry.
4. Behavior when heated (varying widely).
   Temperature of fusion.
   Rate of vitrification (temperature range).
   Shrinkage and loss of volatile parts.
   Color and toughness (strength and hardness) of product.
5. Miscellaneous properties, such as slaking, bonding power, specific gravity, porosity, fineness, feel, odor, taste, homogeneity.

1. PLASTICITY WHEN WET

By plasticity is meant the ability to be molded, and strength to retain the molded form. This property involves the change of form without rupture and at the same time such strength and solidity that when complex forms are built up they may be self-supporting. By virtue of the plasticity of a clay it receives and retains the forms required for great building blocks; at the same time it may preserve the finest lines of the artist's tool.

Unfortunately there is no simple means of determining with accuracy the degree of plasticity shown by clays. But any one who has handled a great variety of clays can quite readily tell whether a clay is of high or low plasticity, and even go farther and distinguish different kinds, as well as different degrees, of plasticity. For example, some clays run smoothly through a die and some will drag at the corners; some are "rubbery" and some waxy. These minor variations, though hard to express, are readily felt by the expert, and the uses of the clay may be in part affected by them. It is common to speak of clays as very plastic ("fat" and "rich"), or "non-plastic" ("lean" and "poor").

In practice, if a clay is too plastic, non-plastic material, usually sand or burnt clay (grog), is added. The preheating work of Bleininger is worthy of consideration and is discussed below under the heading of Effects of Heat. If too lean, a highly plastic clay is added. This is not always satisfactory. If a plastic clay is not refractory, it cannot be added to a lean fire clay without injuring its refractory character. For these reasons other methods for improving plasticity have been sought. Fine grinding may have a beneficial effect. A common method of increasing plasticity is to leave the clay exposed to weather and frost for a season. The exact nature of the effect is uncertain, probably both fineness and the proportion of colloid matter being affected. A third resort is the addition of ammonia or organic colloids, like tannin, or any other solution which by experiment can be shown to give the desired result.

In tempering a clay, water is usually added according to the judgment of the worker. Some clays as dug from the pit are found to be of proper consistency. Various clays and various processes of molding require different proportions of water. The percentage which is present in a clay when at about the consistency to be molded by hand is often called the "water required" or the "water of plasticity." It varies with the judgment of the operator, but is usually reported, as a large amount is an indication of a tendency to crack on drying.

2. SHRINKAGE ON DRYING

There is a strong attraction between clay grains and water. This is so great that in the plastic clay it is usually assumed that there is a film of water on all sides of the clay grain. The drying of such a clay would naturally have an effect on the size of the mass. The outer part of the plastic mass, being exposed to air, gives up its water, and the space between grains either decreases, resulting in a contraction of the mass, or remains open, while air takes the place of water. However, under ordinary conditions the attraction of clay for water causes a readjustment of the water from the interior of the plastic mass. Capillarity draws water from the center toward the drier outside and the lubricating action of the water allows a slight readjustment in the whole mass. As a total result there is the same amount of clay with a smaller amount of water, the films having become thinner throughout without any great change in arrangement. The process may be continued until the clay grains are no longer well lubricated. When the clay grains are actually in contact, the removal of water can no longer bring them closer, but there remains some water in the pores which will gradually be taken into the air and be replaced by air. Shrinkage may be measured as volume or linear shrinkage. It is usually assumed that one may be calculated from the other on the basis of volumes being proportional to the cubes of lines, but this is not always true, as a flat plate of wet clay will dry more rapidly from the large surfaces than from the edges, and the greater part of the shrinkage will be at right angles to the flat surface. Shrinkage varies from 1 to 20 per cent linear measure, and 3 to 45 per cent volume measure.

In the arts the shrinkage of clay is very important. If brick or china ware of certain size is required, allowance must be made by making the molded form just enough larger than the required size. If large masses of clay must be dried or if shrinkage is great, there is often danger that the outside will dry and shrink before there can be the internal readjustment mentioned above. The rate of capillary flow varies with the fineness and distance and other factors. If cracks form, or the shape is badly distorted and warped, the mass is injured if not entirely ruined. The phenomenon is identical with the formation of mud cracks on the surface of a muddy field. In the arts the process is called "checking." If the shrinkage is great, masses the size of common brick must be dried slowly and with great care to avoid cracking. Many clays of good quality in other respects are now neglected because they check so badly. Such clays are often spoken of as "joint clays." They are usually highly plastic and require much water to develop the plasticity. There is, however, no constant relation between shrinkage and plasticity. The sandy clays and flint fire clays and kaolins show little shrinkage. The accepted remedy for checking is the addition of just such material as corrects excess plasticity, viz., sand or grog (burnt clay) or other non-plastic material.

3. TENSILE STRENGTH

Tensile strength is usually spoken of as the measure of the strength of dry clay. The strength of wet clays is not tested except in connection with plasticity. Probably a more useful test would be a measure of crushing strength, as the clay ware is more often subjected to pressure than to tension in building the kilns, but usually a clay of good tensile strength is strong enough, and the test is more easily made by following roughly the standard methods of testing cement. The tensile strength of clays varies from 30 to 350 pounds per square inch; 100 is enough for most purposes. From the plastic state to the dried state the tensile strength increases continuously. Clay grains, originally separated by films of water, have been left in intimate contact by the evaporation of that water and at last adhere to each other strongly. The gluelike nature of any colloids that may have been in solution also manifests itself as the water is removed.

4. EFFECTS OF HEAT

These are so complex that the subject must be subdivided. In outline the effects are:

A. Plasticity, tensile strength, and shrinkage are decreased by slight heating.
B. A series of volatile products are given off.
C. Important reactions take place.
D. Fusion occurs, in a progressive manner, to be studied at several stages.
E. Quality of the product, including colors, shrinkage, toughness, hardness, strength, etc.

A. EFFECT OF PREHEATING

Bleininger,[1] at the Bureau of Standards, has made an exhaustive study of the effects of temperature up to 400° C., in the hope of correcting the defects of "joint" clays, those which check or crack badly in drying. His results show that between 250° and 300° C., there are changes in most clays, chiefly a decrease in shrinkage, plasticity, and the amount of water required. Subject to various limitations for which reference must be made to the original, where they are clearly discussed, the method offers very valuable commercial possibilities in Minnesota, since there are immense bodies of joint clay in the Red River Valley—Lake Agassiz silt.

B. LOSS OF VOLATILE MATTERS IN HEATING CLAYS

The hygroscopic moisture is usually almost completely removed from the clay ware before it is placed in a kiln for firing. During firing a series of products is removed, depending somewhat on the impurities present. The most prominent constituents driven out are water, hydrocarbons, carbon dioxide, and sulphur, and they require different degrees of heat for their removal. Oxygen may be given off or taken into the clay as a result of conditions of firing.

The result at red heat is an increase in porosity without much change in the size or strength of the ware. A too rapid increase of temperature and evolution of these gases may break the clay mass, with explosive violence, even injuring the ware near by. Snapping of this sort is seldom troublesome if care is used in removing water. The burning of the organic matter produces heat, like the addition of more fuel, and may cause a sudden rise in temperature when not desired. Normal colors at this time are red, for clays containing iron. At a temperature only a little higher, the carbonates, chiefly that of calcium, begin to give off carbon dioxide and leave a chemically active lime residue in the clay. Sulphur may be evolved and oxidized from sulphides like pyrite at low temperatures, but it will not be evolved from sulphates like gypsum until very high temperatures are reached. If fusion begins before all these

[1]Bleininger, A. V., Preheating of clay: Bull. Bur. St., Vol. 7, No. 2, 1910.

gases are evolved, the clay mass will swell and become vesicular or "blebby," and be ruined.

C. CHEMICAL REACTIONS

Aside from the reactions mentioned, yielding volatile constituents, there is a complex condition as regards oxidation and reduction, depending on the supply of fuel and air, and, as the temperature of the kiln rises, reaching the fusion point of some compound present in the clay, reactions of various sorts occur. The teachings of physical chemistry also make it clear that reactions may occur producing a liquid from two solids which are in contact even if the temperature is not high enough to melt either. The familiar example is a mixture of ice and salt, which is liquid below freezing temperature. In clays, lime and silica are examples of such substances. The fused material later acts as a solvent, in which other minerals are absorbed, and at this high temperature in fluid or semi-fluid condition is chemically more active than before. As silica is the chief acid present, the main products are silicates usually of indefinite mixed composition. After the firing the solidification of these melted parts of the clay yields the rocklike quality of the finished ware. These melted silicates form the cementing material between the more solid grains. They are largely responsible for the character of the final product.

D. FUSION

The formation of the fused silicates above discussed does not take place instantaneously, but progresses as the temperature increases. The first liquid to form, if kept at the temperature of formation, may dissolve a considerable portion of the surrounding material without itself becoming less fusible. If the temperature is raised, other minerals and combinations reach the point of fusion, and other materials are dissolved in the melt.

The effect on the clay is, therefore, to be studied as a progressive matter, not as a sudden change of conditions from solid to liquid. Three stages are usually noted. The "temperature of fusion" is usually that of viscosity under no load. Fusion under load[1] is a test applied only to refractory clays.

I. At incipient fusion only a few minerals and combinations have fused. If the fused parts are abundant, the whole mass will cool to a product that cannot be scratched with a knife, so that the hardness of the product is the common sign of incipient fusion. This degree of fusion

[1]Bleininger, A. V., and Brown, G. H., The effect of heating fire clays under load conditions: Trans. Am. Cer. Soc., Vol. 12, p. 337.

causes very little shrinkage. Common brick usually require no further heat. Fire clays are not often burned even to this stage.

II. At vitrification enough of the clay has fused so that pores between unfused grains are nearly all filled, but the unfused portion still is abundant and the fused portion is so viscous a liquid that the ware keeps its shape. Shrinkage is usually high. A large amount of high-grade ware is burned to vitrification, or very near it. Porcelain and chinaware, roofing tile, paving and foundation brick, and sanitary ware, are usually vitrified, and some of them are also glazed. This makes the ware impervious to water. Many vitrified bricks are used also as building brick since they are durable and resistant, and many of them have a fine color.

III. At the point of viscosity the unfused particles in the clay are surrounded and suspended in the fused and liquid portion, and the brick flows, destroying the original form. When brick have been piled in a kiln and burned to the approach of viscosity, they may stick together, and, if deformation is not too great, the breaking up of the resulting mass may give blocks of about the size and shape of brick with the rough irregular fracture of broken stone. Such brick can be used in producing many artistic effects and have become quite popular as "klinker brick." The actual temperature of viscosity, commonly noted as the fusion temperature, ranges widely.

Range of vitrification.—Most important in testing a clay to find its applicability to different processes of manufacture is the range in temperature from incipient fusion to viscosity. In firing a kiln full of clay ware the combustion chambers cannot be so distributed as to give an absolutely uniform temperature throughout. Well-made, expensive kilns can approach closely to that uniformity, but there is always likely to be a variation of a few degrees. If it was desired to fire a brick to vitrification at 1200° C., it would be likely that the top or bottom courses would reach only 1160° and the brick nearest the fire might reach 1240°. If the point of incipient fusion was only 40° below the point of vitrification, the underburned brick would not be salable. But if the incipient fusion was 100° to 200° below vitrification, there would be every reason to expect that all the brick fired to within 40° of the point of vitrification would be so nearly vitrified that they would be entirely satisfactory. On the other hand, if viscosity was reached at 1240°, the brick near the fire would be waste, while if not reached for 200° after vitrification, the brick burned to 1240° would no doubt be of good quality. The losses due to underburning and overburning may be as high as 30 per cent of the kiln.

The importance of this determination of the range of temperature during fusion has led to a careful study by R. C. Purdy[1] resulting in recommendations for tests of porosity and specific gravity as a measure of vitrification. The diagrams (Figs. 8, 9, 10, and 11) give a general idea of the method used in distinguishing the applicability of a clay from its behavior. By firing bricklets of clay to several different temperatures and determining their porosities, a curve can be drawn to show the rate of vitrification. The position of this curve as compared with Purdy's diagram, will indicate the applicability of the clay. (See Chapter V.) Much more commonly one judges the behavior of a clay by simple inspection of the bricklets burned to several different stages. A knife will easily show whether the clay has been burned so that it cools to a hard product—to the temperature of incipient fusion. The stage at which viscosity is reached is shown by the deformation of the bricklet. If these are widely separated in temperature, the clay can be safely vitrified. The temperatures to which common clay wares are burned are shown in the following table, in terms of Seger cones.[2]

[1]Purdy, R. C., Paving brick clays of Illinois: Illinois Geol. Sur., Bul. 9, pp. 277-8.
[2]Seger cones are small cones of clay and salts mixed so that they soften or collapse at definite temperatures.

SEGER CONES

	Fusion Point			Fusion Point	
No. of Cone.	Cent.	Fahr.	No. of Cone.	Cent.	Fahr.
022	590	1094	8	1290	2354
021	620	1148	9	1310	2390
020	650	1202	10	1330	2426
019	680	1256	11	1350	2462
018	710	1310	12	1370	2498
017	740	1364	13	1390	2534
016	770	1418	14	1410	2570
015	800	1472	15	1430	2606
014	830	1526	16	1450	2642
013	860	1580	17	1470	2678
012	890	1634	18	1490	2714
011	920	1688	19	1510	2750
010	950	1742	20	1530	2786
09	970	1778	21	1550	2822
08	990	1814	22	1570	2858
07	1010	1850	23	1590	2894
06	1030	1886	24	1610	2930
05	1050	1922	25	1630	2966
04	1070	1958	26	1650	3002
03	1090	1994	27	1670	3038
02	1110	2030	28	1690	3074
01	1130	2066	29	1710	3110
1	1150	2102	30	1730	3146
2	1170	2138	31	1750	3182
3	1190	2174	32	1770	3218
4	1210	2210	33	1790	3254
5	1230	2246	34	1810	3290
6	1250	2282	35	1830	3326
7	1270	2318	36	1850	3362

Common brick	Cone 012—01
Hard burned common brick	1— 2
Buff face brick	5— 9
Fire proofing	03— 1
Terra cotta	02— 8
White earthen ware	8— 9
Fire brick	5—14
Porcelain	11—13
Sewer pipe	3— 7

E. QUALITY OF THE PRODUCT

After cooling from the heat treatment the quality of the product can be tested in various ways. The various steps in the process of heating have important effects. *Color* will be due largely to the presence of iron, or sometimes to manganese, but in the firing it will be modified by the oxidizing or reducing gases and by the degree and temperature of vitrification. *Shrinkage* becomes notable at the beginning of fusion, is complete at thorough vitrification, and is followed by swelling in some cases if gases are evolved after the formation of much glass. The *hardness, strength,* and *toughness* are all low until the fusion begins; then the quantity of glassy cement becomes the controlling factor; at vitrification the *character of the glassy cement* becomes the dominant factor. The hardness of burned clay is usually tested by comparison with tempered steel.

MISCELLANEOUS PHYSICAL PROPERTIES

The slaking of a clay is the tendency of a dry lump to absorb water and fall to pieces when immersed. Clays which slake promptly are easily rendered plastic without fine grinding.

The bonding power of a clay is its ability to hold in suspension less plastic material and to render the whole mass plastic and strong. It is usually, but not always, good, if plasticity is high.

The properties of specific gravity, porosity, fineness, feel, and color of raw clays have less certain connection with the uses or availability of the clays and, though there may be some relationships, no one has yet stated an exact system by which one may judge the useful properties from them. The fineness of grain probably affects the fusibility and rate of fusion of impure clays, but this is less notable in high-grade clays.[1]

Homogeneity might be considered a physical property and is of importance in the application of clays to industries, as the variable clays need more careful selection and mixing.

[1]Hofman, Trans. Am. Inst. Min. Eng., 1898.

CHAPTER III

CLASSIFICATION AND ADAPTABILITY OF CLAYS

THE BASIS OF CLASSIFICATION

Various classifications of clays have been proposed for various purposes. Commercially, the uses of the clays are the basis of names. Geologically, the origin is important. Technically, the physical properties of the clay are most distinctive.

CLASSIFICATION BY USES

The uses of clay are listed by H. Ries as follows:[1]

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

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

Hygienic.—Urinals, closet bowls, sinks, washtubs, bathtubs, pitchers, sewer pipe, ventilating flues, foundation blocks, vitrified bricks.

Decorative.—Ornamental pottery, terra cotta, majolica, garden furniture, tombstones.

Minor uses.—Food adulterant; paint fillers; paper filling; electric insulators; pumps; fulling cloth; scouring soap; packing for horses' feet; chemical apparatus; condensing worms; ink bottles; ultramarine manufacture; emery wheels; playing marbles; battery cups; pins, stilts, and spurs for potters' use; shuttle eyes and thread guides; smoking pipes; umbrella stands; pedestals; filter tubes; caster wheels; pump wheels; electrical porcelain; foot rules; plaster; alum.

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

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

Of these, the uses of sufficient importance to give variety names to clays are:

Class Names on the Basis of Uses

Fire clay	Brick clay	Paper clay
Slip clay	Glasspot clay	Tile clay
Stoneware clay	Paving brick clay	Sewer pipe clay
Saggar clay	Paint clay	Pottery clay
Terra cotta clay	Adobe clay	China clay

These terms are rarely used in a restricted sense. The same term may be applied to widely different clays. Different terms may be applied to similar clays. It is hoped that they will be used less as the properties of the clays are better known.

[1]Ries, H., and Kümmel, H. B., Clays and clay industry of New Jersey; Final Report of State Geologist, Vol. 6, pp. 213-4.

CLASSIFICATION BY GEOLOGIC ORIGIN

In the discussion of geologic processes the following classes may be mentioned:

Class Names Based on Geologic Origin

- I. Residual
  - a. From igneous and metaphorphic rocks
  - b. From sediments
- II. Colluvial
- III. Transported
  - a. Marine
  - b. Estuarine
  - c. Lacustrine
  - d. Alluvial, flood plains and terraces
  - e. Glacial
    - 1. Till
    - 2. Lacustrine
    - 3. Alluvial
    - 4. Loess
- IV. Metamorphosed slates

CLASSIFICATION BY PHYSICAL PROPERTIES

In the classification on the basis of physical properties, it is desirable to select the most important of the properties for first divisions and the less important ones for subdivisions. Of the physical properties discussed above, plasticity, strength, and behavior in the fire are most noteworthy, and of these the fusion phenomena are fundamental. If the plasticity or strength are not satisfactory, the deficiencies may be corrected by additions of suitable proportions of other clays. If the range of vitrification is too small, it is very difficult to make a proper addition to correct it.

Class Names Based on Physical Properties			*Main Uses*
I. Refractory (above cone 27)	Earthy, usually residual, non-plastic		China clay
	Plastic		Ball clay
	Flint-like, non-plastic		Fire clay
II. Semi-refractory (above cone 10)	Safely vitrifying	red burning	Sewer pipe Paving brick
		buff or cream burning	Stoneware
	Rapidly fusing		Low grade fire clay
III. Non-refractory (below cone 10)	Safely vitrifying	red burning	Drain tile Foundation brick
		buff or cream burning	Vitrified brick Foundation and sewer brick
	Rapidly fusing		Common brick

Subdivisions of II and III may be made on the basis of degree of plasticity, or some other physical character.

RELATION OF PHYSICAL PROPERTIES TO USES

Common brick clays should be fairly plastic and should burn hard below cone 1 (2100° F.). The product should have a pleasing color. Higher plasticity is required for stiff-mud than for soft-mud brick.

Clay for front brick should be somewhat more plastic so that the brick may hold their form better and present smooth surfaces and square corners. The color after burning is a more important matter in this case. Such brick are nearly always burned so hard that they cannot be scratched with a knife. They should have a good range of vitrification to avoid heavy losses from deformed brick.

Brick with a glazed surface, allowing the original color to show through, or with an enamel, an opaque coating, with its own color, need not be very different from common brick, if the fused coating is so adjusted as to expand and contract with the body of the brick. If the expansion of the body is different from that of the surface, the two would crack away from each other on cooling.

Hollow brick and *fire-proofing blocks* are made to secure lightness in weight. Other properties being equally good, the lighter and more porous product is the more desirable. The clay must be plastic enough to work in an auger machine with a die for the hollow center. Often, if the bonding power is good, it is desirable to add sawdust to increase the porosity. The dried clay must have moderate tensile strength. The burned color is immaterial, but the red blocks are usually ferruginous and somewhat heavier than the lighter colored ones. The burning must produce strength and durability in the product, rather than hardness, density, or beauty.[1]

Clay products to withstand temperature changes when wet.—Foundation brick, sewer brick, and sidewalk brick, all of which are often subject to frost, differ from common brick only in the degree of vitrification. These must be so well vitrified that water cannot enter in such a way as to disrupt the brick on freezing. It should be possible to vitrify the clay almost completely—to a porosity of only 4 or 5 per cent—without leaving many soft brick or many viscous deformed brick in the kiln.

Paving bricks and blocks require the same kinds of material as foundation, sewer, and sidewalk brick, but with the additional quality of toughness of the product. This is even more important than completeness of vitrification. From some clays the toughest brick are obtained by stopping the heat before vitrification is complete. There is no way to foretell from the composition and raw properties of the

[1]Specifications have been formulated and can be found in Eng. News, Vol. 47, p. 248.

clay whether or not it will yield a tough product. It is necessary to try them, in actual practice, by several methods.

The clays for drain tile are similar to those used in making stiff-mud brick. The form of a tile is such that there is a strong tendency to warp and crack in drying. If the molded form does not warp on drying and does not show auger laminations, it will probably make good drain tile.[1]

Wall and floor tile should be made from clays similar to those used for hard paving bricks, and, in addition, the product should have a pleasing color.

Terra cotta clay must be very highly plastic and very strong to retain the complex ornamental designs imposed upon it. The clay is usually selected with great care to obtain uniform color and a strong product free from cracks. The clay should have a good range of vitrification, but usually is not burned very hard.

Clay for sewer pipe must be much like that for paving bricks. The product is not subject to the same severe abrasion, but the forms are so large and thin-walled that high strength is a necessity. Only a small amount of shrinkage is allowable, as warping and cracking are fatal defects. A dark colored product, usually obtained by a salt glaze, is demanded by the market.

Clay for porcelain, pottery, china, and other domestic and sanitary ware, requires the highest degree of preparation and control. It must be plastic and free from sand. As a rule it is washed to remove impurities. It must be strong to hold its shape and it must not shrink so much that it warps. It must burn white, or very light, and partially vitrify without danger of losing its form. The range should be over 200° F. The product should be tough and strong. When a glaze is to be applied, the thermal expansion should be the same as that of the glaze, to prevent cracking.

Refractory clays must primarily stand at high temperatures in the structure desired, and sometimes they are subjected to repeated heating and cooling without losing their strength and infusibility. Many of the refractory clays are non-plastic, and ordinarily one does not expect high plasticity or much strength of the product. But if these are too weak, additions of plastic clay or bonding material must be made even at the expense of fusibility. In some furnaces ware with very coarse grain and open texture is wanted in order to prevent rapid conduction of heat. Such ware is formed by the addition of large amounts of crushed burned clay—grog. In other furnaces clay is desired which burns to a very

[1]Tests for good drain tile have been formulated by the Am. Soc. Testing Materials. Proceedings, Vol. 11, p. 833.

strong dense body at medium temperature, but does not weaken or soften until a very high temperature is reached.

Slip clays must primarily melt to a smooth glaze at a temperature lower than that of the body on which they are to be used, and must be fine grained so as to remain suspended in water indefinitely.

METHODS OF TESTING CLAYS

In estimating the availability of a clay the procedure is as outlined below. The reports contributed by the U. S. Bureau of Standards were obtained by similar methods.

1. *The working quality* is determined by dropping a lump of dry clay into water to determine whether it slakes at once. Bricklets were molded by machine or by hand presses; shrinkage was estimated from the volumes before and after drying. The need of care in drying was estimated from the strength of the briquettes dried slowly and those dried rapidly. Mr. F. M. Handy has developed also, in connection with this work, a test of adhesion to show the danger of defective structure, if the clay is molded in a stiff-mud machine. (See Plate II A.)

2. *The behavior in firing* was tested in a large kiln with several bricks fired to different temperatures. (See Fig. 3.) Color, hardness,

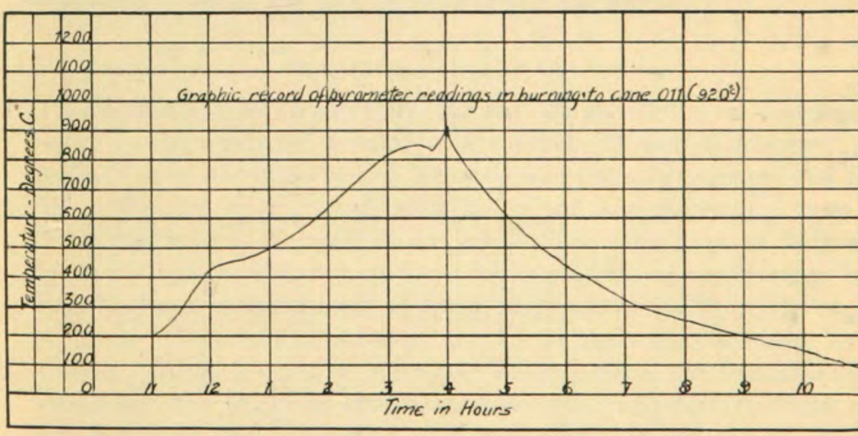


FIGURE 3. TIME-TEMPERATURE CURVE OBTAINED IN BURNING TESTS (REPORTED HEREIN).

and porosity were noted after firing. Hardness was tested by comparison with Mohs' scale, and the brick are said to be "steel hard" or have a hardness of 6, when they cannot be scratched with a knife. Most important of the characters is the range between the temperature where the clay begins to vitrify and the temperature where so much has melted that the brick loses its shape. This range of vitrification determines whether or not a clay may be burned to a hard product successfully, for if a clay becomes viscous at a few degrees above the temperature where it begins to fuse, it is almost impossible for the entire kiln to reach the point of incipient vitrification before some of the brick have melted.

3. *Special tests.*—Refractory clays were tested in a Meeker Muffle, and some impure clays were washed, as nearly as possible by the methods commercially successful. A few analyses were made. Slip clays were applied to a semi-refractory clay after preliminary firing. Tests of fineness were conducted on a few clays with a series of sieves.

4. *Tests of clay products* made in Minnesota were confined to brick and hollow tile. Transverse tests were made on thoroughly dry brick and modulus of rupture calculated by the usual formula. Absorption tests were made by weighing the brick first when thoroughly dry, and later after they had been boiled in water four hours. Crushing tests were made on five wet and five dry bricks.

CHAPTER IV

TECHNOLOGY OF CLAYS

PROSPECTING

THE USUAL METHOD OF PROSPECTING

Most developed deposits of clay have been found by men in other pursuits, who had the requisite knowledge and skill to observe the signs about them and investigate what others would pass by unheeding. One who has become familiar with the appearance of one clay will recognize a similar material elsewhere. A plowed field, an excavation along a road, a well, a post hole, or the bank of a stream, may reveal valuable clays. Most common clays lie near the surface and may be found by examining any place where the soil has been removed. If there are no such places, a dirt auger with an extension handle is the simplest means of making excavations. Some clays, however, do not lie so near the surface and are not so easily discovered. Yet if they are fire clays, or kaolins, it may still be worth while to develop the deposit if it can be discovered. Other methods of prospecting are useful.

THE METHOD OF STRATIGRAPHY

The method of stratigraphy has for its foundation an assumption which is fairly reliable, if used with caution. Where sedimentary formations lie in nearly horizontal layers, it may often be assumed that they are continuous underground, even if the soil and vegetation have accumulated so that the rock is concealed. The logic may be illustrated by an example in Minnesota. The rock formations of southeastern Minnesota, where well exposed, at many places show bluffs at the top of which is a limestone containing such fossils that it is identified as the Galena. Below it come in order the Decorah shale, the Plattville limestone, and the St. Peter sandstone, each with a definite thickness and character. If near Faribault, for example, there should be a number of such exposures, of uniform character, and at the particular place where it is desired to use the Decorah shale no outcrop occurred except the Galena, it would be safe to conclude that under the surface the Decorah exists as it does in other parts of the neighborhood. (See Fig. 4.) This assumption is useful in finding some clays. A line of springs along a hillside also often gives evidence of clays underground.

More rarely, when conditions seem to warrant it, drill holes and shafts are sunk to considerable depths in search of clays.

WHERE TO PROSPECT

Common clays are so widely distributed in Minnesota and in most other states that the choice of a deposit depends principally on the marketing conditions. To be valuable, clays must be near a market or near some line of easy transportation. Some very excellent clays in this State are destined to remain untouched for years because they are too inaccessible. At the present time it will not pay to haul fire clay or pottery clay by wagon to any distant railroad point for shipping. The price last year for good fire clay placed on the car was about $1.25 per ton, and a wagon haul would consume any profit at that price.

In connection with the market and commercial considerations, the cost of labor, fuel, and other material should be considered. A few high grade clays may overcome the handicap of unfavorable market conditions.

WHAT TO DETERMINE

After studying market conditions and finding a clay, before a plant is erected one should determine, first, the amount and distribution of clay; second, its general character; third, the conditions of working; and, if all these are favorable, finally, the purposes for which the clay is suited. Each of these deserves the most careful attention.

LOCATION OF PLANT

The exact location of the buildings and yards with respect to the clay pit is a matter which deserves more attention than is usually given it. In examining a large number of clay deposits, one cannot but be impressed by the numerous examples of yards and buildings which have been built over the best clay in the deposit. The plant should be arranged so that the material progresses from pit to machine, to drying racks, to kiln, and to shipping point, in regular sequence, without any great distance between points, and without a return over ground once passed.

WINNING THE CLAY

Open pits are most common. Underground work is too expensive except for kaolin and fire clays. The pick and shovel are used on most clays. With uniform clays requiring no selection in the pit, a plow and scraper are often used, and in large plants the steam shovel is most economical. Any overburden is removed by similar methods. Drainage is an item of expense in some places.

TRANSPORTATION

Only the most valuable clays of Minnesota are shipped by rail to the

A. A BURNED BRICK SHOWING AUGER LAMINATION.
A BURNED BRICK SHOWING EFFECT OF PEBBLES.

B. SLATE AT THOMPSON, SHOWING BOTH CLEAVAGE AND BEDDING.

plant. A cable car is much the most common method of bringing the clay to the machine.

PREPARATION

Some clays are sent directly from the pit to a machine for mixing and molding, but a rather large number are improved by some preliminary process. Plasticity may be improved if the clay is weathered. Many clays cannot be worked until crushed and ground; and often with the grinding, the clay is passed over screens to remove the larger pebbles. High grade clays are often washed to remove some coloring matter and sand. If clays are to be mixed or if additions are to be made for changing the color or character of the clay, the work is usually done before tempering. The pre-heating referred to in the chapter on Physical Properties is recommended for those clays that crack on drying. The tempering may be conducted in plain soak pits dug near the machine, in more elaborate ring pits, in wet pans, or in pug mills. In the manufacture of pottery more care is needed and the process is closely controlled by the individual worker. The washing and molding processes in use at Red Wing are described in the report on Goodhue County.

THE HUTCHINSON PROCESS FOR PEBBLY CLAYS

The gray drift which is so widespread over Minnesota requires a cleansing treatment before it can be used for the manufacture of high grade ware. The limestone pebbles are causes of the chief defects. After the clay is burned, the limestone particles slake, swell, and destroy the brick. There are several ways in which a clay containing such pebbles can be made useful. First, if the limestone is not too abundant, fine grinding may be sufficient to remedy the defect. Second, by fairly fine grinding, and immersing in water, after removal from the kiln, the lime is rendered harmless.[1] Third, by drying and gently grinding, so that the clay is disintegrated and the harder pebbles left, it is possible to catch most of the limestone on a screen, through which the clay passes. Fourth, by using machines for removing pebbles from a clay in a plastic condition.[2] Fifth, and most important, is a washing process. This process is emphasized because a plant in Minnesota, using material that can be found in nearly every part of the State, has made a commercial success of the process.

At Hutchinson, in McLeod County, the gray drift is cleansed of limestone pebbles by a process that is probably not duplicated in America. This process has been developed by Mr. M. C. Madsen, who has

[1]Binns, C. F., Trans. Am. Cer. Soc., Vol. 14, p. 218.
[2]The Diesner clay cleanser: Brick, Vol. 31, No. 5.

been experimenting on it for many years. The actual machinery of washing is comprised in a space not over 20 feet square and 15 feet high, and washes 130 yards of clay in a day. The clay from the bank is hauled by cable car to the washer. Here it is mixed with an excess of water and agitated by a series of vertical rods fastened to a rotating cross beam. The harrow-like motion of these rods has a tendency to throw the larger pebbles toward the center of the washer, while the fine clay and sand remain suspended and distributed throughout the pit. Near the center of the pit a bucket elevator of continuous operation dips into the pit and removes the gravel. At the sides of the pit an opening covered with a screen of the proper mesh allows the escape of the fine sand and clay. These are conducted to one of the series of open ponds in which they are allowed to settle. After a time some of the water may be pumped off and the rest is left to sink into the ground. The sand naturally settles close to the intake of the pond and the clay is carried to the farther side of the pond. After partial drying it is ready to be taken to the stiff-mud machine where the clay and sand are mixed in approximately the same proportions in which they existed in the drift before the washing. The gravel is sold for concrete. Both the clay and sand contain a considerable amount of calcium carbonate, but, if care is taken that the coarser sand is removed, no damage is done by the impurity, and it is certainly less abundant than in the unwashed drift. The plant at Hutchinson makes use of three round down-draft kilns, and plans are made to double the capacity. It has been found possible with this clay to produce a very good drain tile and hollow building block, so that the production of common brick has become a secondary matter. The drain tile are of excellent quality and are famous for their ability to withstand freezing.

A large plant of this character, shipping its product over a large territory, would meet competition with plants using clay free from limestone pebbles, and, therefore, more cheaply worked. For a local plant of medium size, however, there is promise of success, and there is room in the western and northern parts of the State for several such plants. See the reports on Pipestone and Douglas counties.

MOLDING

Brick are molded either as very soft mud by hand or machine; or as stiff mud by an auger machine; or nearly dry by a press. Sometimes after molding and partly drying, brick are sent to a press to be improved in form and structure. A common defect in structure is shown in Plate II A. Most hollow ware is molded by a stiff-mud process. Sewer pipe are made of stiff mud, but with an intermittent press instead of a continuously acting auger.

Pottery is molded by several processes, some of it being hand molded, some turned on a wheel, some pressed in plaster molds, and some "cast" in plaster molds.

The process of glazing is sometimes conducted by adding a coating on the surface of the ware as molded, but in less valuable ware is brought about in burning by the addition of salt vapors.

DRYING

The supply of air and the temperature must be regulated usually so that the ware is not dried too fast at first. This would crack most clay ware. Many devices are made use of to regulate the rate. Brick are commonly dried in open air or under sheds, sometimes on racks. Some brick and the more complex wares are dried in tunnels with artificial heat, or in large drying rooms.

BURNING

The kilns used, fuel burned, and temperature desired are diverse. Probably nine-tenths of the bricks burned are simply piled on a level place with arched spaces left for fire at the bottom and open work enough in the body of the kiln for the heated gases to rise through. The outside layers may be piled close and plastered with mud to keep the cold air out. The fuel is often wood, though coal is used at some plants. This is a *scove kiln.* A kiln with permanent walls may be an improvement on this, but usually if a wall is built, the arrangement of fire box and chimney are altered so that the heat of the fire goes first to the top of the kiln, and, passing down through the bricks, leaves by a flue at the bottom. This is the *down draft kiln.* It may be round or oblong. Pottery is burned in kilns with arrangements for keeping the combustion gases away from the ware. The pottery is often surrounded with fire clay boxes—saggars—to keep it from contact with the flames. Gas is a desirable fuel. For economy in heat, many attempts have been made to devise *continuous kilns,* where gases passing from one combustion chamber are conducted to another to warm it up, preliminary to combustion in that chamber.

The burning process may be arbitrarily divided into three parts: (1) dehydration; (2) oxidation; (3) vitrification. Dehydration always occurs and in some clays requires considerable time. Oxidation takes place only in those clays containing iron or organic matter or both. The process of oxidation may take a large amount of time and the ware must be kept at a good red heat until it is finished, before any attempt is made to raise the temperature to the beginning of the melting process—or vitrification. For if the clay begins to melt before oxidation is complete, the ware is almost certain to swell and puff out of shape and be discolored inside. More losses and trouble are due to mismanagement at this stage than at any other. During vitrification the clay begins to melt and the liquid formed fills the spaces between unmelted grains, reducing the porosity. Good vitrification makes a product that will be much more resistant to frost and abrasion than material not vitrified.

Minor features of burning worthy of mention are glazing, flashing, and the formation of efflorescences. Glazing is sometimes accomplished by throwing salt on the fire when the kiln is at its hottest. Flashing is a process by which the color of the products containing iron can be brightened and changed depending on the regulation of the supply of fuel and air. Efflorescences may appear on brick after burning. They are due partly to salts concentrated on the surface during drying, but partly also to the action of combustion gases in the kiln.

USE OF THE PRODUCT

The method by which a brick wall or pavement is constructed has a great deal to do with the satisfaction it gives. With drain tile, also, it is known that the method of placing the tile is an important factor in the success of drainage. The purchaser of clay brick and tile should not be content to get good wares, but should see to it that they are properly used.

The advantages of the use of clay products are fairly well known. The excellent quality of the paving brick clays and drain tile clays in this State should especially favor the use of local material for these purposes. There will undoubtedly be an increasing demand for both paving and tile.

CHAPTER V

GEOLOGY OF MINNESOTA WITH SPECIAL REFERENCE TO CLAYS[1]

PHYSIOGRAPHY

Minnesota exhibits a series of morainic belts and partially filled kettle holes, alternating with more gently undulating belts of modified glacial drift, and several large lake beds, the most notable of which are those of ancient Lake Agassiz in the northwestern part of the State and the delta deposits of the glacial Lake Superior. Rock hills rise in rounded masses through the drift in a few points, mostly in the northern part. In the extreme southeastern corner is the driftless area, occupying portions of a few counties, where outcrops are more frequent, although most of the surface has been covered by a veneer of loess from 1 to 12 feet thick, averaging about 4 or 5 feet. This loess tends to smooth over any small irregularities in the surface.

The principal drainage system is that of the Mississippi River and its intricate net of tributaries. In the northwest the Red River of the North constitutes the main drainage basin. A small area drains into Lake Superior.

GEOLOGIC HISTORY

The rocks of Minnesota range in age from the earliest Archean granites and schists to the Recent alluvium. The accompanying table, Plate VI, arranged in order of age with the oldest formations at the bottom and the youngest at the top shows the principal formations found within the State.

The oldest known formation in Minnesota is the Ely greenstone of Archean age, occurring in the northern part of the State. It is probably for the most part of igneous origin. Much of it has been metamorphosed to a schist and the remainder is so altered by pressure and folding and igneous intrusions that its original character is effectively obscured. Before the end of Archean time sedimentary rocks were deposited and intrusions of granite magmas forced their way upward. These now occur as enormous masses of granite and gneiss in the older Archean greenstones and schists. With the processes of sedimentation came the deposition of material rich in iron and processes began to operate which

[1]Credit for the main features of the discussion of the geology is freely given to N. H. Winchell and Warren Upham, Final Reports of the Minnesota Geol. and Nat. Hist. Survey. Also to C. W. Hall and O. E. Meinzer who contribute some new data on southern Minnesota in Water-Supply Paper, No. 256, U. S. Geol. Survey.

resulted in the formation of great bodies of iron ore. Many of the granite intrusions of this time were of such great extent that little of the intruded rock is now in evidence.

Following the Archean period came the deposition of a great series of sediments over most of the northern part of the State and large parts of the south. After their deposition they were metamorphosed by pressure and both acid and basic rocks were intruded. These sediments and intrusives make up the Algonkian system.

Near the close of Algonkian time, the basic Keweenawan rocks were erupted mainly as an immense series of flows. This igneous activity was followed by further sedimentation and erosion until Paleozoic time, when, with the advance of the sea, conditions became favorable to the formation of sandstones, limestones, and shales. These covered most of the State except the northern and northeastern parts. During Paleozoic time the area emerged for a period and was then again submerged, for there is an unconformity between the Ordovician and Devonian. The close of the period is marked by a complete emergence.

Following the emergence of the land after the Devonian, there came a long period of erosion and weathering through the latter part of Paleozoic and most of Mesozoic time. The Cretaceous sea, in which all the next sediments were deposited, encroached upon the land from the west and gradually spread eastward, partially submerging the older rocks, all except the highest ridges, which extended above the sea to form islands. The rocks appear to be of Dakota or Benton age, in terms of the formations known farther west. There is here a pronounced unconformity. The Cretaceous rests directly upon the much-weathered Archean surface in many places. The conditions under which such decomposition of granite could occur must have been the long continuous weathering of a region of comparatively low relief, for had the surface been one of much relief, erosion would have removed the soft decomposition products.

After the recession of the sea in late Cretaceous time the region has not again been submerged. Much of the Cretaceous was probably eroded before the invasion of the continental ice sheets, and much more of it was removed by this glacial erosion.

PLEISTOCENE

By Frank Leverett, of the United States Geological Survey

In Minnesota the Pleistocene deposits show a peculiarly complex history, there being not only recurring stages of glaciation separated by long stages of deglaciation, but also a complexity of ice movement in a given glacial stage. There was one movement into Minnesota from the northwest, another from the north, and a third from the northeast in the latest of the glacial stages (the Wisconsin), and possibly there was similar complexity in earlier stages. These movements were not synchronous in their advance, culmination, and waning, but instead each had its own time of waxing and waning. The interpretations of these complex conditions are incomplete as yet, and the relations of ice lobes set forth in the accompanying glacial map are at best only approximate.

(1). The oldest glacial deposit, the pre-Kansan or Nebraskan, is so completely buried beneath later deposits that it is not drawn upon in the clay industries so far as known to the writer. The attenuated edge of this drift may be exposed in the southeastern counties.

(2). Deposits of a clayey and silty character have been found in a few places at the junction of pre-Kansan and Kansan drifts which represent accumulation in the Aftonian interglacial stage. They are, however, of slight thickness and limited extent and rarely seen in either natural or artificial cuts and hence not likely to figure in the clay resources of the State.

(3). The Kansan drift is extensively exposed in the southeastern part of the State and also in part of Pipestone and Rock counties in the southwestern. It is generally of clayey texture, but seldom is sufficiently free from stones to be considered valuable in clay industries. It contains local pockets or lenses of marly pebbleless clay which may prove of value in these industries.

(4). The results of subaerial action on the Kansan drift have been of some importance to the clay industries. Through the agency of wind much of the surface in the southwestern corner of the State and part of the southeastern has become coated to a depth of several feet with loess. This pebbleless deposit, composed of fine dust that settled over these districts, has been used widely in brick and tile manufacture in other states and may be so used in this State.

(5). The Wisconsin drift so far as developed by the movement of ice from Manitoba in its course across western and southern Minnesota, is largely of clayey texture, but, like the Kansan drift, it contains usually too many small stones to be of value for brick or tile. These stones, moreover, are largely limestone and especially unfavorable constituents because of slaking in the process of manufacture of brick or tile. There are lenses and pockets of pebbleless clayey material included in the stony clay which may become of limited value locally. Furthermore, this drift where freed from limestone pebbles by the Hutchinson process, described on page 25, becomes a satisfactory material for manufacturing brick and drain tile.

(6). The Wisconsin drift, so far as developed by movement of ice from the north or northeast across eastern and central Minnesota, is largely stony and coarse-textured and unsuitable for use. Very rarely there are silt or clay pockets in it.

(7). The lake silts laid down in bodies of water in the western Superior and Red River basins are locally thick enough to be used in clay industries, the plants at Wrenshall being a conspicuous instance. Ordinarily there is a thin deposit of lacustrine sediment in the deep pools of these old lake beds, but in certain localities it is replaced by sand, while on the borders of the basins the bowlder clay and the gravelly beach ridges are prevalent surface features.

(8). In addition to the great glacial lakes of the Superior and Red River basins, there were numerous small lakes or ponded areas along the border of the ice, in which silt was deposited. Such an area occurs north of Princeton at the large plants of Brickton, and similar areas occur farther east along the northern edge of the lobe of ice that extended northeastward from the Mississippi to the St. Croix Valley above the Twin Cities.

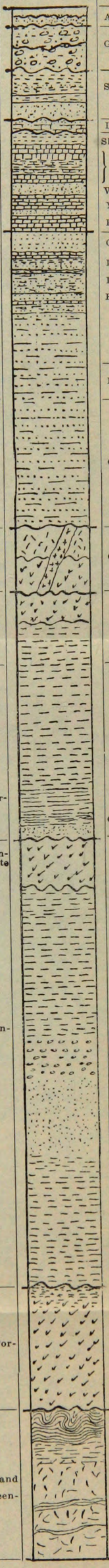
Since the retreat of the ice there has been only a slight modification of the surface and very little accumulation of material or removal by erosion. A few lakes and swamps have been filled and a few have been drained. The large river channels have been silted up.

GEOLOGIC FORMATIONS AND ASSOCIATED CLAYS

ARCHEAN SYSTEM

The rocks belonging to the Archean system which are known in Minnesota consist of greenstones, granites, gneisses, schists, and jaspers. They underlie all other formations everywhere and constitute the basal member upon which the subsequent strata were laid down. In northern Minnesota these Archean rocks include the productive iron-bearing formation of the Vermilion Iron Range. In the western part of the State hornblende and biotite schists and granites are known to underlie the Cretaceous formations in many localities where they outcrop or have been encountered in deep wells. Granite and gneiss outcrop in central Minnesota and are known by well records to underlie the greater part of southern Minnesota.

In the southwestern portion of the State where the Archean rocks are covered by Cretaceous sediments, they are invariably decomposed near the top to a white clay. Evidence of this is clear in the numerous wells throughout the region, in addition to the occasional outcrops. The clay extends downwards in some instances to a depth of fifty feet, where it grades into soft rotten granite of various shades. The upper portion of the residual clay also grades into the Cretaceous sedimentary clays



Era	System and series	Formation	Character of Strata	Aprox Max Thickness Feet	Clay-bearing Value
Cenozoic	Quaternary: Recent		Alluvium, etc.		Contains alluvial clays
Cenozoic	Quaternary: Pleistocene		Glacial drift, bowlder clay, sand, gravel, modified drift, etc.	600±	**Contains large amount of good clay**
Mesozoic	Cretaceous	Benton Shale	Soft blue and gray shale; incoherent sands;	550	Contains much high grade clay
		Dakota Sandstone	white sandstone and white clay		Fire clay
Paleozoic	Devonian		Limestone & sandstone	100	Contains thin beds of clay
	Ordovician	Maquoketa Shale	Shale, dolomite, and sandstone	100	Contains but little clay-shale
		Galena Limestone	Limestone and shale	350	Contains but little clay-shale
		Decorah Shale			Contains large amts. good clay
		Platteville Limestone			Contains no clay
		St. Peter Sandstone	**White & yellow sandstone; some shale**	200	Contains no clay
		Shakopee Dolomite	Yellow, buff, pink, or red dolomite	75	Contains no clay
		Oneota Dolomite	Buff to Reddish dolomite	200	Contains no clay
	Cambrian	Jordan Sandstone	Coarse grained white sandstone	200	Contains no clay
		St. Lawrence Formation			
		Franconia Sandstone	Dolomite, shale, sandstone	130	Contains small amount of shale
			Impure sandstones	100	Contains no clay
		Dresbach Sandstone and underlying shales and sandstones	Fine grained white sandstone; shale and limestone beds toward base	450	Contains some sandy shales
	Algonkian (?)	Red clastic series	Red sandstone and shale	2,000	Contains little available clay or shale
Proterozoic	Algonkian: Keeweenawan	Conglomerate and sandstone	Conglomerate and sandstone	200	Contains little available clay
		Eruptives	Gabbro diabase & granite	unknown	Contains no clay of value
	Algonkian: Huronian Series: Upper Huronian (Animikie group)	Acid and Basic Intrusives		unknown	Contains no clay
		Virginia and other Slates	Black to dark gray carbonaceous slates	3,000±	**Contains no clay except residuals** **Slates may be used after crushing**
		Biwabik and Gunflint Formations	Taconite, iron ore, ferruginous chert & paint rock	800±	
		Pokegama Quartzite	Quartzite and quartz slate with conglomerate at base	200	
	Algonkian: Huronian Series: Lower-middle Huronian	**Giants Range and other Intrusive Granites, Granite Porphyry and Dolerites**	Gray and pink granite, granite porphyry, dolerites and lamprophyres	unknown	Contains no clay
		Slate Graywacke and Conglomerate	Green to gray slates, graywackes and conglomerates	5,000	Contains much slate but no clay
	Archean: Laurentian	Granites, Gneisses and Porphyries	White clay decomposition product		Contains large amounts of residual clay and kaolin beneath the drift
			Granites and porphyries in part altered to schists	unknown	
	Archean: Keewatin	Soudan Formation	Banded cherts and red jaspers		
		Schists and Porphyries and Ely and other Greenstones	Greenstone, green schists Porphyries and iron ore	unknown	Contains no available clay

GENERAL GEOLOGICAL SECTION OF MINNESOTA

so that the dividing line has rarely been determined. It is more than probable that in some cases where great thicknesses of residual kaolin are reported, some Cretaceous clay is included. Much of the residual clay is of excellent quality. Outcrops are known chiefly along the Minnesota Valley from New Ulm up to the vicinity of Montevideo. Well records show this type of clay in Big Stone County at a depth of 250 to 600 feet; in Chippewa County at depths of about 700 feet; in Lac qui Parle County at 150 feet; in Lyon County at 200 to 600 feet. Probably the clays are extensive and more or less continuous in the counties north and west where well records are not available.

The following analyses of the clay, and one of the clay after washing, are available:

Table I. Analyses of Residual Clays.

	1	2	3	4	5
Silica	43.86	45.92	41.71	62.04	37.88
Alumina }	41.82	39.84	34.61	25.54	26.96
Ferric oxide }			4.58 }	1.89	15.78
Ferrous oxide }			6.88 }		
Magnesia }	very small	very small	0.22		1.74
Lime }			1.16		trace
Soda	n. d.	n. d.	0.11 }		0.95
Potash	n. d.	n. d.	trace }		
Water	14.65	14.12	12.69		15.88
			101.96		

1. Clay from Morton. F. F. Grout, analyst. See U. S. Geol. Survey, Water Supply Paper, No. 256, p. 310.
2. Clay washed from a decomposed granite, Redwood Falls. F. F. Grout, analyst. U. S. Geol. Survey, Water Supply Paper, No. 256.
3. Clay from decomposed gneiss, Birch Cooley, near Morton. A. D. Meads, analyst.
4. Clay partially analyzed by L. B. Pease.
5. "Fahlunite." Average of three analyses by S. F. Peckham. Described in Minnesota Geol. and Nat. Hist. Survey, Vol. 2, p. 196.

It is hoped that this widespread residual clay may be used after a washing process as a kaolin for porcelain and china-ware products. A rough washing test in the laboratory on a few widely separated samples shows that about 50 per cent of the crude product can be washed through a 100-mesh sieve. This finer portion of the clay burns to a clear white and even after being glazed shows very little darkening of the color. These clays are the most refractory in the State and are capable of being used for the highest grade of clay products. (See also Figs. 8 and 9.)

ALGONKIAN SYSTEM

This system is subdivided into the Keweenawan, Upper Huronian, and Lower-Middle Huronian. Each of these groups is separated from the other by a marked unconformity.

The lower-middle Huronian is not known to include clays, but consists of granites, granite porphyries, dolerites, slates, graywackes, and conglomerates. The sedimentary series attains a thickness of 5,000 feet in the northern part of the State.

Upper Huronian.—There are a number of distinct formations belonging to this series. These include the following: (1) Pokegama quartzite; (2) Biwabik and Gunflint iron formations; (3) Virginia slate and slates and schists near Carlton and Little Falls; and (4) acidic and basic intrusives. Besides these there is the Sioux quartzite, thought by some to be equivalent to the Pokegama, while others place it in the lower-middle Huronian.

Outcrops of these rocks are confined to the central and northeastern part of the State except those of the Sioux quartzite, which are in the southwest portion. The slates cover the largest area and attain great thickness. (See Plate II B.)

None of these rocks contains any clay deposits of importance, but experiments made in connection with this report show that some of the slates exposed in Carlton County, when crushed and mixed with a small amount of common clay from the drift, will make a beautiful fancy brick of high quality. In the Sioux quartzite are some layers of a silicified shale known as pipestone. No single body of it is over four feet thick, and it is of no importance in ceramic industries. Some ferruginous layers of clay in the Biwabik formation are called "paint rock." This paint rock does not melt at as low a temperature as might be expected from its iron content, and, where mining operations make it necessary to remove it, it may be made use of for brick. Residual clays from mica schist outcrop along the Mississippi River in Morrison County, and, though they are not as refractory as those from the Archean, they fuse at a relatively high temperature.

The Keweenawan from the eastern and northeastern parts of the State is largely made up of basic igneous rocks with no clays. Some flows alternate with sediments, which are not, however, of a quality suitable for use as clay. At Two Harbors, on the north shore of Lake Superior, lenses only a few feet in length and a few inches thick were sampled to determine their character. Along Snake River just below Pine City a rather large bed of essentially the same material occurs. The clay does not slake or become plastic. It remains sandy and soft to a temperature of 2300° F.

Sediments, known as the "red clastic series," and probably of the same age as the Keweenawan igneous rocks, are known in the eastern and southeastern parts of the State and have been provisionally assigned to the Algonkian (?) system. These underlie sediments of Upper Cambrian age in the south, and are known only from well records. They are probably of the same age as the red sandstones and shales outcropping from Lake Superior southwest to Mora which lie unconformably over the Huronian and are locally called Hinckley sandstone. Shaley layers are especially abundant near the base of the formation. An analysis of this shale from near Fond du Lac is reported in the discussion of Carlton County.

CAMBRIAN SYSTEM

The Cambrian system embraces in order of age (the oldest being first), shales and white sandstones, underlying the Dresbach sandstone, the Franconia sandstone, the St. Lawrence formation, and the Jordan sandstone.

The lower formations, including the Dresbach and Franconia sandstones, are made up of 450 feet or more of fine-grained white sand with shaley beds and sandy shales and thin layers of limestone towards the base. The best exposures are to be seen along the St. Croix River north of Stillwater and at Dresbach on the Mississippi River just north of the Iowa line. Siliceous shales of variable character occur at these places, but are not likely to be of importance as clays.

St. Lawrence formation.—This consists of buff-colored dolomite interbedded with shale and sandstone. The shale is greenish in color and towards the top of the series there are several thin layers of green sand. The total thickness of the formation is about 225 feet. The best outcrops are found along the Mississippi and Root rivers, north of the Iowa line, although the St. Lawrence underlies practically all of southeastern Minnesota extending as far north as northern Washington County and westward to a point beyond Mankato, where it outcrops in the Minnesota River Valley. The shales are too thin to be important as brick material. They are so sandy that there is very little shrinkage up to the point of viscosity.

Jordan sandstone.—The Jordan sandstone consists of white to brown sandstone and has no clay. The thickness ranges from about 75 to 200 feet. It is confined chiefly to the southeast corner of the State, and it is well exposed in the Minnesota River Valley north of Mankato and in the bluffs along the Mississippi from Hastings to the Iowa line.

ORDOVICIAN SYSTEM

The Ordovician system in Minnesota is composed of the following members, the oldest being placed last:

6. Maquoketa shale
5. Galena limestone

4. Decorah shale
3. Platteville limestone
2. St. Peter sandstone
1. Prairie du Chien group (Shakopee dolomite and Oneota dolomite)

All of the Ordovician rocks are confined to the central and southern part of the State, where they rest conformably upon the Cambrian. Their attitude is almost horizontal, although they have a slight dip in general to the southeast.

Prairie du Chien group.—The Oneota dolomite is a buff to reddish dolomite which outcrops in numerous localities along the valleys and river bluffs in southern Minnesota. The texture of the rock varies from granular to crystalline, the latter variety being more typical. The thickness ranges from 75 to 200 feet. No clay is associated with the formation.

The Shakopee dolomite contains no clays, but consists of a maximum of 75 feet of yellow, buff, or red magnesian limestone which differs from the Oneota in texture and color and includes some sandy beds. It is finer grained and more granular. The Shakopee outcrops along the Mississippi and Minnesota river bluffs and in much of south central Minnesota forms the surface upon which the drift has been deposited.

The St. Peter sandstone consists in the main of a fine-grained, loosely consolidated white sandstone which often presents a yellow surface where it has been exposed to weathering. In thickness it ranges from 80 to 200 feet, the average being somewhat over 100 feet. In most parts of southern Minnesota the St. Peter is covered either by late Ordovician sediments or by the drift, or by both, but it outcrops along the Mississippi and its tributaries from Minneapolis south.

There is a 4-foot bed of shale above the sandstone of the St. Peter and below the main Platteville limestone, but it is too thin to be of value.

The Platteville limestone has an average thickness of 12 or 15 feet, although a maximum of 30 feet has been observed. The rock is a magnesian limestone, varying in texture from granular to thoroughly crystalline, and in color from buff to blue-gray. It outcrops over large areas in southern Minnesota from the Twin Cities southeast. It contains no clay of value.

The Decorah shale.—Lying on top of the Platteville limestone is a series of green shales with a maximum thickness of nearly 100 feet, though the average thickness is much less, probably 50 feet. Interbedded with these shales are numerous layers of hard granular limestone, some of which are composed almost entirely of fossils. In some places these limestone layers constitute more than one-half of the total thickness of the formation. The limestone beds vary in thickness from an inch to several feet, but most of the layers are less than one foot thick. At the base is usually a thick shale about 10 feet, but above this the shale and limestone alternate in similar layers. The shale is fissile and crumbles easily. The extent of the shales is shown on the map (Plate I.) The line sketched is intended to show the limits of workable shale and not necessarily a definite horizon. Since the upper part of the shale grades into limestone, to the south,[1] a map of the horizon is of little economic importance. The northern and eastern limits are outcrops. On the west and south the Cretaceous and Devonian rocks overlap the Decorah and make it inaccessible. Even in the area mapped the glacial drift covers some of it so deeply that it may not be profitably worked. In the extreme southern part of the State the formation thins out to about 30 feet. From Cannon Falls as far as St. Paul the maximum thickness is observed. North of St. Paul the formation is eroded away. Throughout the southern part of the State its elevation above sea level ranges from 1,000 to 1,300 feet, on account of very gentle folding. It is flat-lying wherever noted. The Decorah is one of the most important clay formations in Minnesota. The shales, when crushed and pulverized and mixed with water, yield a greenish plastic clay which is used extensively near St. Paul and in Goodhue County for the manufacture of pressed brick, fancy brick, hollow ware, drain tile, and common brick. The St. Paul plant is most favorably situated with respect to market, but, besides the plants already operating, there might be room for developments at Faribault, Rochester, and Cannon Falls. The high grade of the product eliminates most of the competition of common brick. In general, the shale burns red, but can be turned green and brown and mottled by reduction during firing. It needs a much lower temperature for vitrification than most clays—about 1800° F.—but has a good range, so that it can be well vitrified without loss. The material and process have not been manipulated to produce a paving brick, though this may yet be possible. The upper layers differ slightly in color and behavior from the lower ones. Stiff-mud machines and presses are most successfully used in working the shale. Figs. 8 and 9 show the behavior during vitrification.

The shale rarely outcrops, and the stratigraphic method of prospecting should be applied. The top of the shale is likely to be a persistent spring horizon, and grass usually covers the slope. The topographic relation of the shale and limestone is shown in Fig. 4. Analyses are re-

[1]Sardeson, F. W., Galena series: Bull. Geol. Soc. America, Vol. 18, pp. 179-94.

ported in Table VI, in the discussion of Dakota County. Tests made by the Engineering Department of the University of Minnesota show that bricks made from the Decorah shale are of excellent quality. Soft red brick, not burned to vitrification, have a strength of 1,500 pounds per square inch; partly vitrified bricks with a rather high porosity still evident, have a strength of over 3,100 pounds per square inch.

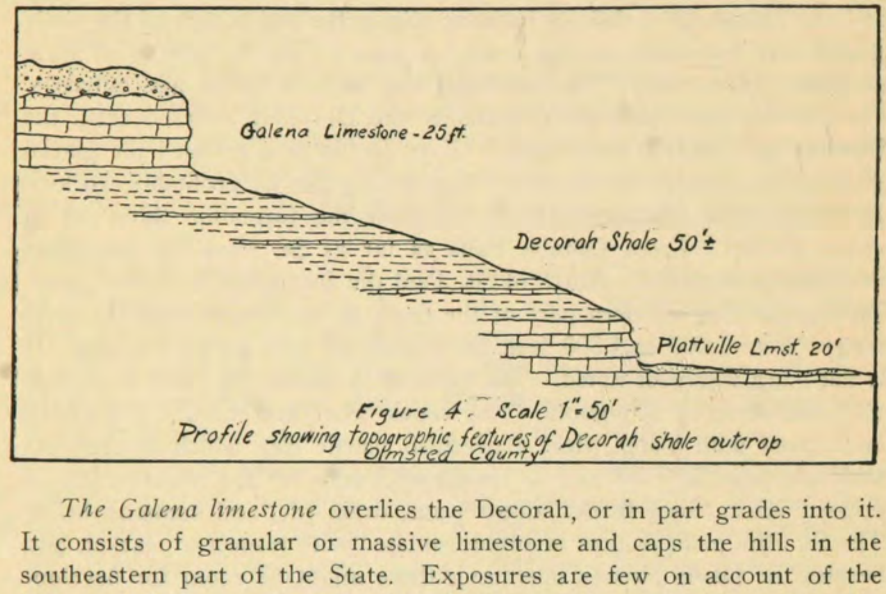


Figure 4. Scale 1" = 50'
Profile showing topographic features of Decorah shale outcrop Olmsted County

The Galena limestone overlies the Decorah, or in part grades into it. It consists of granular or massive limestone and caps the hills in the southeastern part of the State. Exposures are few on account of the loess and drift covering. In typical outcrops there are only a few thin shale beds of no value. A sample was taken southwest of the town of Chatfield, Fillmore County. The layers are but a few inches thick and could hardly be obtained free from limestone. Fragments of the dry shale slake in three minutes to a mass of small lumps. Its plasticity is fairly high. It requires 22 per cent of water for molding. Its air shrinkage is 5 per cent. At low temperatures the burning resulted in a salmon-colored product without any fire shrinkage, and with an absorption of about 28 per cent. It becomes buff and hard at cone 4 (2210° F.) and turns gray at cone 6 (2282° F.), but is still undeformed at even higher temperatures, though wholly melted at cone 12.

The Maquoketa shale is in Minnesota an alteration of dolomitic shale and limestone with shales too thin to be of value. Outcrops are known only in Fillmore County where the formation has a maximum thickness of 80 feet. The dry clay slakes in 10 minutes. Its plasticity is fairly high and it requires only 15 per cent of water for molding. Its tensile strength is about 100 pounds per square inch and its air shrinkage less than 3 per cent. It could safely be dried with artificial heat. In burning up to a temperature of cone 2, several samples were buff in color without any fire shrinkage and with an absorption of 27 per cent. It does not become hard at cone 3 (2174° F.), but it has become viscous at cone 6 (2282° F.). It is, therefore, impracticable to burn this clay to a hardness approaching vitrification. This is the only sample of Maquoketa shale available.

DEVONIAN SYSTEM

The Devonian rocks in Minnesota consist of sandstone and limestone and shales, the total thickness of which is not more than 100 feet. They are confined to the extreme southern part of the State where they constitute extensions of the Devonian formations more general in Iowa. In the vicinity of Austin, marly layers of the Devonian have been used to mix with the plastic clay which overlies them. The lime in the added marl improves the working quality and gives a product with lighter color.

Where Bear Creek crosses the line between Fillmore and Mower counties, shale beds were found to be as much as one foot thick and there is every indication that they extend over considerable territory. They are yellow to buff in color, very sandy and lean, and, of course, could not be separated commercially from the interbedded limestone. The shales slake in about four minutes and develop a surprising amount of plasticity considering their sandy appearance. They require about 20 per cent of water for molding. Their tensile strength is nearly 100 pounds per square inch. They can be dried rapidly without danger and retain their tensile strength even after being separated as by an auger and pressed together. The air shrinkage is about 3 per cent. At very low temperatures the burning tests yield a salmon-colored product, but at the higher temperatures buff colors prevail.

Cone. No.	Color	Per Cent Shrinkage	Per Cent Absorption
06	Buff	......	27
2	Buff	1	23
5	Buff	......	......

The clay becomes hard at cone 03 (2000° F.) and viscous at cone 6 (2282° F.).

CRETACEOUS SYSTEM

Wherever the Cretaceous rocks are found in Minnesota, they consist of soft sandstones, shales, and clays, and, locally, have thin beds of conglomerates at the base. They cover most of the western part of the State, below the drift, and numerous scattered areas occur throughout the southern, central, and northern portions. Outcrops are few on account of the drift cover, but numerous well records have helped to determine the general distribution. The maximum thickness is about 500 feet in this State. The upper portion is composed chiefly of soft blue or gray shales and clay, while deeper down white sandstone and kaolins are encountered. In the northern part of Minnesota there are a few occurrences of Cretaceous conglomerate at the base of the shale overlying beds of iron ore. The pebbles in the conglomerate are composed of hard hematite. In the western part of the State the Cretaceous rests upon the decomposed Archean granites and gneisses. There the base of the shale is white clay with conglomeritic or concretionary texture and contains quartz pebbles. In a few places where the Cretaceous lies in contact with Paleozoic sediments the conglomerate is not prominent, but the clays are similar to those just mentioned. The variation of the conglomerate with the bed rock is an indication that the white clay has been transported only a short distance.

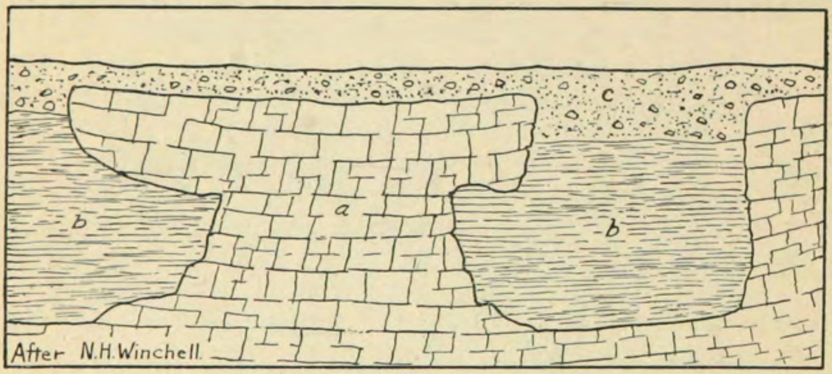
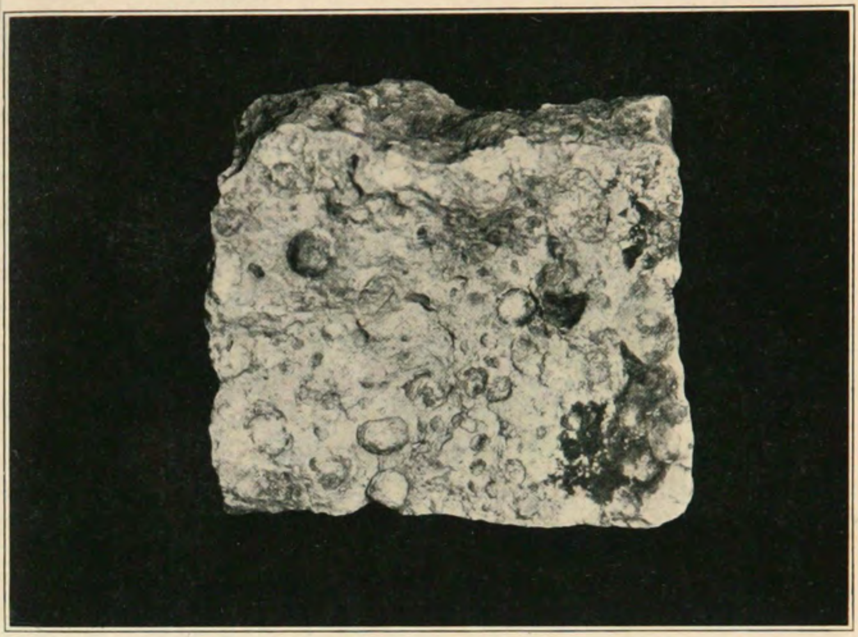
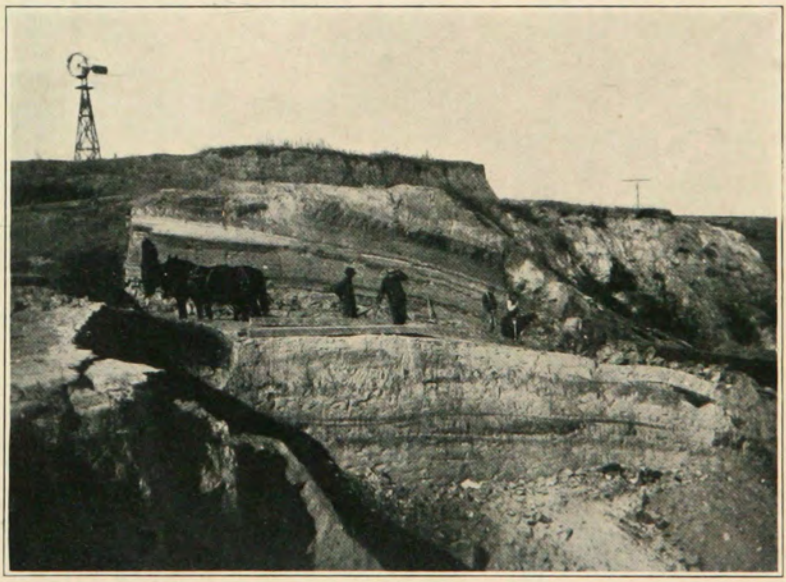


FIGURE 5. SECTION SHOWING THE OCCURRENCE OF CRETACEOUS CLAY NEAR MANKATO. *a*. SHAKOPEE DOLOMITE. *b*. CRETACEOUS CLAY. *c*. DRIFT.

The Cretaceous beds contain the highest grade clays to be found within the State. Some of them are used for stoneware, pottery, sewer pipe, and fire brick. At present there are but few areas of Cretaceous clays known where a good body of material lies close enough to the surface to be profitably excavated, but it is very probable that more detailed prospecting in the drift in the vicinity of Cretaceous areas would result in the discovery of new deposits of valuable clay. For convenience in discussion of the clay deposits the basal part of the formation where pebbly or concretionary will be treated separately, and it will be



A. BASAL CRETACEOUS CONGLOMERATE, NATURAL SIZE.



B. CRETACEOUS CLAY IN THE PIT AT CLAY BANK, GOODHUE COUNTY.

necessary to refer often to the Archean residual clays which cannot everywhere be sharply distinguished. The higher formations have the common characteristics of marine or lacustrine sediments.

The basal Cretaceous clays.—These are most prominently exposed along the Minnesota River in the bluffs on both sides of the valley from Granite Falls to New Ulm and probably extend to Mankato. (See Figs. 5 and 6.) Under the drift white clays of apparently similar character are found through several counties on either side of this strip along the river. The great extent under the drift is further confirmed, and the certainty that these deposits are not entirely Archean residuals is shown by occurrences near Richmond in Stearns County, and near Bowlus in Morrison County. There is a general variation in the character of these basal Cretaceous clays as traced through these outcrops and farther north. Where

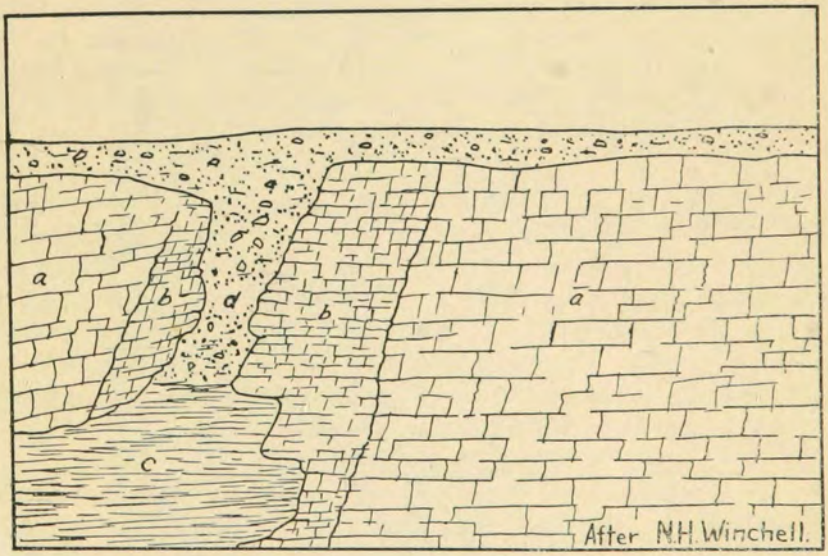


FIGURE 6. SECTION NEAR THE RAILROAD BRIDGE, MANKATO.
a. SHAKOPEE DOLOMITE. *b*. WEATHERED LIMESTONE.
c. CRETACEOUS CLAY. *d*. DRIFT.

Archean or other bed rock formations are feldspathic in character, the basal conglomerate consists largely of clay. On the iron ranges, immediately overlying the Huronian iron ore deposits the Cretaceous basal conglomerate is good iron ore. At Bowlus the basal Cretaceous has the appearance of an iron-stained clay and analysis has shown it to be high in iron. This gradation in widely separated outcrops may be taken as some slight indication of the continuity and contemporaneous formation of the various materials. The clays which outcrop in the Minnesota Valley, however, are peculiar in their texture and contain numerous beds or layers, varying from one foot to many feet in thickness, which appear to be concretionary and have the appearance of bauxite. The rounded spots show very little concentric structure, are at some places more highly colored than the matrix, and at others less highly colored. (See Plate III, A.) In a few very instructive outcrops these rounded spots, which appear to have the same composition as the matrix, were associated with rounded pebbles which proved to be quartz. It is therefore concluded that not all of them are concretionary in their origin. It is possible that part of them are concretionary and part are water-worn fragments. Possibly the original pebbles were quartz and feldspar, the latter having been subsequently altered, as the bed rock below has been altered. Analyses of several samples with intent to show the content of bauxite resulted negatively. In the sample from Bowlus (see Morrison County) there was certainly too much alumina for the mineral kaolinite, so that there is some probability that concretionary bauxite originated during or after the formation of the basal Cretaceous conglomerates. The later Cretaceous shales overlie these beds with a very abrupt change in lithologic character.

Summarizing the properties of the basal Cretaceous clays, we may say that they are usually highly refractory, fine-grained, and rather siliceous, and sometimes heavily stained with iron. Their plasticity is medium and their tensile strength is rather low. The shrinkage both in drying and burning is very small. They burn hard at temperatures ranging from cone 06 to cone 35. It seems very likely that the whiter samples could be washed to produce a kaolin fit for china ware. Analyses are reported in the discussions of Morrison and Redwood counties. (See Figs. 8 and 9.)

The Upper Cretaceous shales.—These shales are supposed to underlie much of the western part of the State, but are heavily covered with drift over most of the area. The eastern border cannot be accurately mapped on account of the drift cover. Beyond it there are many outliers and patches which have been transported by ice.[1] (See Plate III, B.) Some of the most valuable deposits in the State are of this age. In places the shales are interbedded with sandstone and, less often, with limestone. Nearly all of the shales are gray in color, but some have a greenish tint. They are exceedingly plastic with a peculiar waxy feel, owing apparently to the presence of some mica scales in the clay. The clay beds overlie the basal conglomerate with an abrupt change in

[1]Sardeson, F. W., So-called Cretaceous of southeastern Minnesota. Jour. Geol. Vol. 6, p. 679.

color. Many of them are contaminated with organic matter, and many are somewhat ferruginous. The thickness of any occurrence of this shale depends largely upon the amount of subsequent erosion which has occurred. Outcrops ranging from 1 to 50 feet in vertical banks have been seen. Well records reveal a much greater thickness under the drift. A peculiar occurrence is shown in Figs. 5 and 6. In the southern and southeastern parts of the State they are known to be semi-refractory, but the western and perhaps the northern deposits are more uniformly ferruginous and not of so great value. Nearly all of the Cretaceous shales have a good range of vitrification and can be burned hard without danger of fusion.

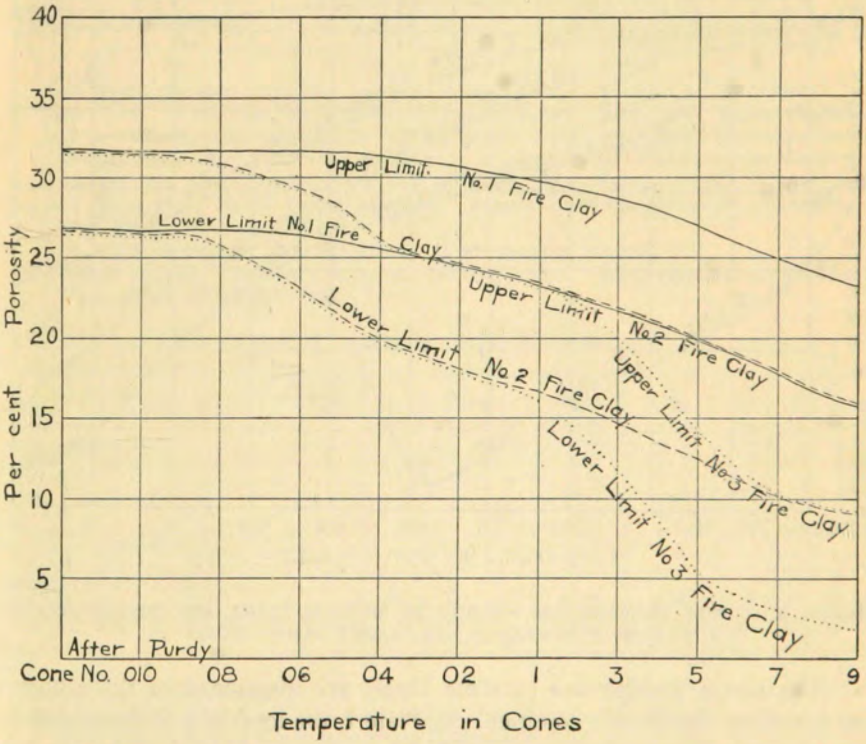


FIGURE 8. CURVES SHOWING THE LIMITS OF POROSITY OF FIRE CLAYS AT VARIOUS TEMPERATURES.

Summarizing the properties of the Cretaceous shales, we may give the following averages. The water required for molding is 27 per cent. The air shrinkage is less than 7 per cent. The plasticity is satisfactory and the tensile strength is high enough for the production of any of the complex forms constructed in the most elaborate of the factories in this

State. Upon burning, many of the clays become dense and hard below 2000° F. The shrinkage on burning to thorough vitrification is only about 4 per cent. The absorption is rarely as high as 10 per cent after the clay becomes hard. Several of the clays, though burning very dense, give indications of withstanding high temperatures without losing their strength. See Figs. 8 and 9 for the behavior during vitrification.

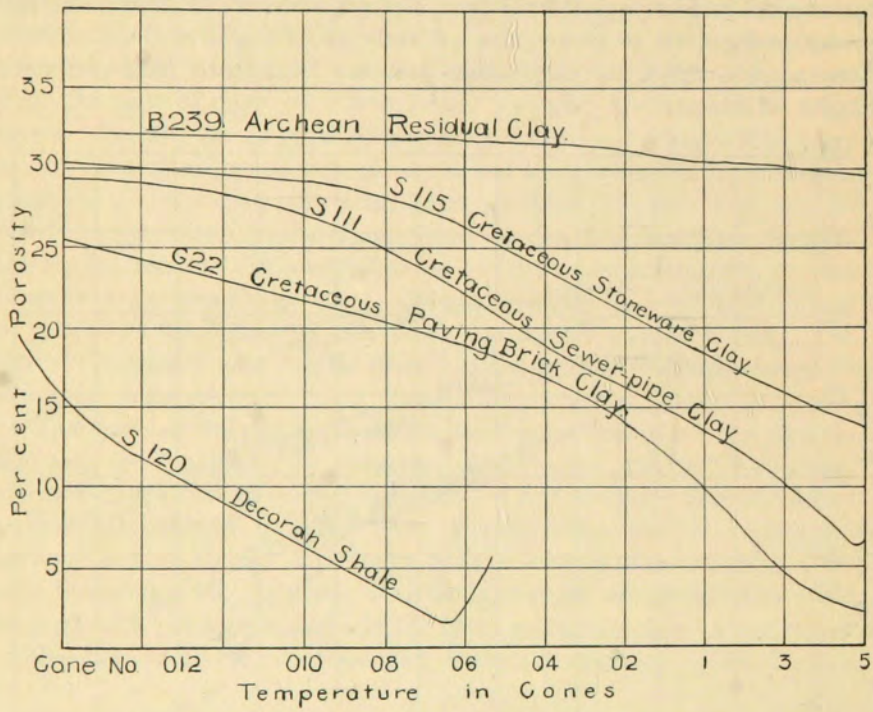


FIGURE 9. CURVES SHOWING THE POROSITY OF RESIDUAL CLAYS AND PRE-PLEISTOCENE SHALES OF MINNESOTA, AT VARIOUS TEMPERATURES.

The plants making use of these shales are mentioned in the reports on Goodhue and Brown counties. In Plate I, the locations of some plants are shown. The quality of the material used at Red Wing is known by the reputation of the stoneware and sewer pipe. They are both excellent. Bricks are made from Cretaceous shale both by soft-mud and stiff-mud methods. Soft-mud solid red brick show a strength of 3,600 pounds per square inch. Stiff-mud hollow brick, made light in weight for shipping, show compressive strengths from 900 to 1,600 pounds per square inch, depending on how well they are vitrified. The modulus of rupture is from 500 to 1,500 pounds per square inch.

The following analyses of the shales are available:

Table II. Analyses of Cretaceous Shales

	1	2	3	4	5
Silica	69.84	61.32	68.298	69.050	58.14
Alumina	23.07	12.27	18.266	18.830	19.40
Ferric oxide	0.48	3.62	2.867	2.607	5.52
Ferrous oxide	....	4.18	....	....	......
Lime	0.11	.99	.719	.296	0.79
Magnesia	0.14	1.76	.802	.622	1.52
Sodium } Potassium }	trace	.42 3.59	.81 .60	1.066 1.461	.54 2.09
Barium oxide	....	.05	....	....	......
Manganese oxide	....	.27	....	....	......
Phosphorus	....	.27	....	....	......
Sulphur	....	.19	....	....	......
Titanium	....	.66	....	....	.68
Moisture	6.35	....	1.29	.898	2.10
Ignition	....	10.73	6.155	4.912	8.81
	99.99	100.32	99.908	99.74	99.59

1. Red Wing, Goodhue County. Analyses reported by J. H. Rich to H. Ries.
2. New Ulm. Brick clay, U. S. Geol. Survey Bull. No. 60, p. 151. T. M. Chatard. A brick made from this clay is reddish brown, strongly sintered, somewhat fractured. Hon. John Lind took the sample in south bank of Cottonwood River on section line where river crosses, east of wagon road crossing, south of New Ulm.
3. Red Wing clay. C. P. Berkey, analyst. Sample from Minnesota Stoneware Co., Red Wing, April 22, 1902.
4. Red Wing stoneware clay, air dried. C. P. Berkey, analyst.
5. Dakota sample. Clay sampled by A. Parker, Brown Valley, just beyond the state line. F. F. Grout, analyst.

Table III. Analyses of Cretaceous Shales

	6	7	8	9	10	11
Silica	59.72	70.10	87.70	93.65	73.34	68.70
Alumina	30.00	16.99	7.24	2.15	14.75	18.04
Iron oxides	....	trace	trace	0.25	5.45	1.53
Lime	0.82	....	0.67	0.20	0.28	1.24
Magnesia	0.51	....	0.07	0.12	0.05	0.56
Soda	....	....	3.17	trace	trace	0.24
Potash	....	10.69	0.49	trace	trace	5.28
Phosphorus oxide	....	....	....	....	....	0.09
Sulphur trioxide	....	0.23	....	....	....	......
Titania	....	....	....	....	....	......
Moisture Ignition	10.34	1.98	trace	2.25	4.71	1.40
Organic matter	....	....	trace	....	....	trace
	101.39	99.99	99.34	98.62	....	......

6. Ottawa, Ottawa Brick Co. H. Ries.
7, 8, 9, 10, and 11, from Final Rep. Geol. & Nat. Hist. Survey, Vol. 1, p. 438.
7. Near Mankato, clay filling hollows in Shakopee dolomite.
8. Near Mankato, Sec. 20, from "white clayey bed of considerable extent."
9. Near Mankato, Sec. 36. "Nearly white, very fine grained, somewhat friable earth."
10. Same locality, red ochery clay.
11. Near Mankato, clay or shale between Shakopee dolomite and Jordan sandstone in L'Hullier Mound.

TERTIARY SYSTEM

Rocks of Tertiary age have not been identified with certainty in Minnesota, but there are probably thin stream deposits of this age at various places in the State. These Tertiary stream deposits cannot be differentiated from the more recent surficial deposits and most of them have been worked over by more recent streams, or by the ice, and mixed with the material of the drift.

QUATERNARY SYSTEM

Pleistocene deposits

Following the outline of Pleistocene history, as given above by Professor Leverett, we may divide the deposits into the following groups: (1) Nebraskan drift (no clay); (2) Aftonian (only thin clays); (3) Kansan and Wisconsin drift from the northwest—the gray drift; (4) Wisconsin drift from the north and northeast—the red drift; (5) lake clays of laminated structure,—first, those of gray color, or yellow if weathered, and, later, those of red color; (6) the loess. These divisions are based on differences in character, though one division, such as the gray drift, may include material of two or three separate invasions. Furthermore, the red drift from the north is of somewhat different material than that from the northeast, but the associated clays are so much alike that no distinction is made.

AFTONIAN SOIL

Following one of the early drift invasions, vegetation apparently spread over the southern part of Minnesota, and a soil was formed which subsequently was buried under the recent deposits of dray drift. The soil as now found is dark gray in color, and varies from 1 to 4 feet thick. It can easily be traced for perhaps 20 rods along the Rock Island Railroad within 2 miles southeast of Faribault. Two analyses, made in 1906 by F. F. Grout for Professor Leverett, of the United States Geological Survey, are available.

Silica	65.10	55.10
Alumina	10.42	10.60
Iron oxides	4.74	4.47
Magnesia	2.06	2.06
Lime	4.52	7.26
Moisture	1.05	1.58
Ignition	8.10	15.32
Titanium oxide	0.82	0.60
Alkalies, etc., by difference	3.19	3.01

THE GRAY DRIFT CLAYS

Glacial drift with a high proportion of clay and generally, but not always, a gray color and a superficial alteration to yellow, covers over half of the State, having come in from the northwest with lobes which reached in a few places completely across to the eastern border of the State. Reference to the map, Plate I, will show its general distribution. Though the gray drift may be the product of more than one invasion, the clays were derived from the same regions and are of the same type. The older Kansan and pre-Kansan drifts may be more weathered and leached, but no distinction is made in this discussion. The clays are characterized throughout by the occurrence of limestone pebbles, which render them unfit for the production of clay products, unless some process is applied for their removal. This has been done successfully in Minnesota at Hutchinson, where a unique process has developed for washing the gravel out. This is fully described under Technology. Besides the washing process, there is a screening process, and a fine grinding process, either of which may in some cases render gray drift available for making brick.

The drift is usually a surface formation and has no overburden except a few inches of soil. Loess may have accumulated over much of it, but has either been washed away, or mixed with slope wash so as to be pebbly and much like the original drift in nature.

In summarizing the properties of the clay found in the gray drift, we may report the following averages. Twenty-three per cent of water is required for molding. The tensile strength is nearly 100 pounds per square inch, and the material can be rapidly dried without serious injury. The air shrinkage is 5 per cent. The fire shrinkage is only 2 per cent at the time the clay becomes hard, and about 5 per cent just before it becomes viscous. The absorption meanwhile ranges from about 19 per cent down to 6 per cent. The average clay becomes hard at cone 02 (2030° F.), and viscous a little above cone 3 (2180° F.). The range of vitrification is therefore less than 200° and it is usually unsafe to burn the clays very hard. See also Figs. 10 and 11. The stiff-mud process is usually successful. By cleansing the clay of its limestone, the properties can be greatly improved, and the washing or "slumming" process used at Hutchinson and the dry cleansing process used at Jackson are recommended for careful investigation by all who plan to organize any ceramic industry making use of the gray drift. Exceptional locations may be found where a simple grinding process will be satisfactory, but the washing process is much more certain and applies to a much wider range of material. Analyses of washed material are reported in the discussion of McLeod County. As the northern part of the State becomes more settled and as the farmers in various parts of the State find it desirable to install systems of tile drainage, the local demands for a good quality of tile such as can be produced from this gray drift will increase and be so permanent as to warrant the erection of several plants of medium capacity. Such a plant might well make use of about half a dozen down-draft kilns, and nearly every situation in the western half of the State where the demand is at all favorable, will undoubtedly be found supplied with gray drift of the proper quality. The radius through which such a plant would find its market would probably rarely be over 50 miles, but within Minnesota several such plants may well be established. Brick made from washed gray drift are usually salmon-colored and some are buff. The crushing strength, as tested at the Engineering Laboratory of the University, was over 2,400 pounds per square inch. The drain tile made from washed gray drift seem to be exceptionally good in the matter of resisting frost.

GLACIAL LAKE AND RIVER CLAYS: GRAY LAMINATED CLAYS

In many parts of the State and chiefly along the valley of the Minnesota and Mississippi rivers and their tributaries, there are beds of clay which show a very interesting kind of stratification in distinct, nearly horizontal, layers, varying from a fraction of an inch to 8 inches in thickness. These layers are dark blue-gray where fresh, and yellow where they have been exposed to oxidation. (See Fig. 2.) They are often finely laminated with alternating fine sand and rich partings of clay. Plate I shows the location of large deposits and Plate IV shows a typical exposure. There is a tendency to split along the darker partings which are seen to extend continuously without grading into one another. The bedding is nearly level, but may dip a few degrees on either side or even be locally folded into arches or basins. (See Plate V, B.) In some clear exposures there are as many as 60 layers, all nearly alike, in a depth of 15 feet. The alternating conditions which produced them were evidently repeated 60 times without interruption. A probable explanation is that these divisions mark so many years occupied by the deposition of the clay. Along the flood plain of a river, clay would settle only where hollows were formed by inequalities of surface outside the path of the main current. The structure of this clay and its occurrence only in glaciated regions or valleys draining from glacial drift, indicate that the formation was accumulated by streams coming from a melting ice sheet. If this suggestion is correct,[1] it is apparent that the floods would be greater and bring a coarser sediment in summer than in winter, and thus produce the alternating layers found. Such clays have long been known and used along the Minnesota River at Chaska and Jordan, and along the Mississippi River from Minneapolis to Brainerd. (See Fig. 7.) They are calcareous and suitable mainly

[1]Winchell, N. H., Final Rep. Minnesota Geol. and Nat. Hist. Survey, Vol. 1, 1884. p. 467, and Vol. 2, 1888, p. 132.

LAMINATED CLAY, WRENSHALL.

for brick and fire-proofing. The present investigation shows a much wider distribution than has heretofore been reported, and there is every reason to expect that still other deposits will be developed. The leached, upper yellow clay is much more satisfactory than the lower gray clay. The latter cracks badly on drying and the preheating mentioned in Chapter II is recommended.

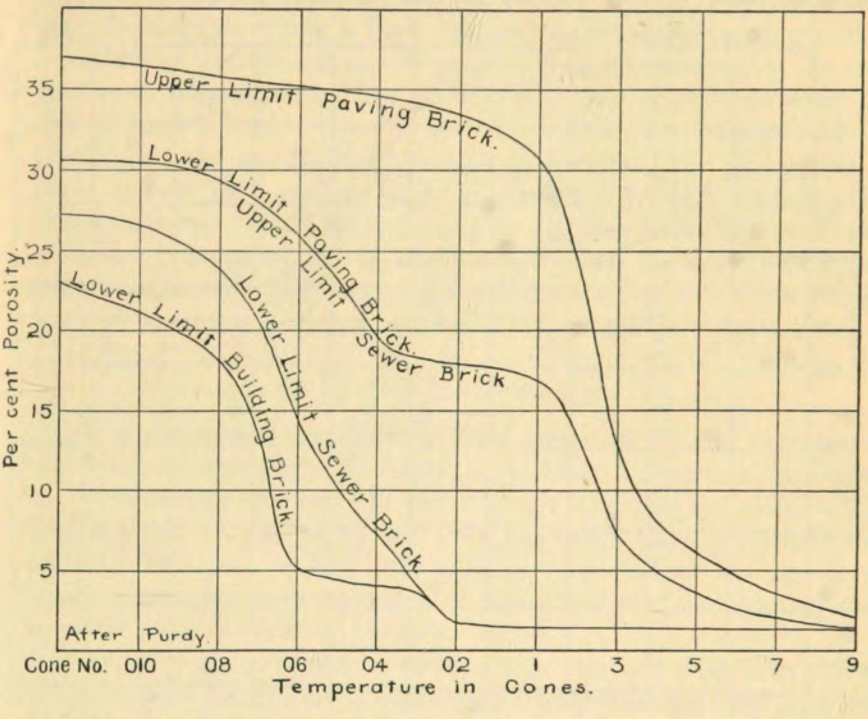


FIGURE 10. CURVES SHOWING THE LIMITS OF POROSITY OF BRICK CLAYS AT VARIOUS TEMPERATURES.

Summarizing the properties of the gray laminated clays, we have the following averages. The clays are rather highly plastic, and require 29 per cent of water for molding. The tensile strength is about 100 pounds per square inch, and is not seriously affected by rapid drying. The air shrinkage is nearly 6 per cent, but this average figure is increased by the presence in the data of some figures for the unused, underlying blue clays. When burned hard, the fire shrinkage is only a little over 2 per cent. The maximum shrinkage observed before the clay reached viscosity will average about 8 per cent. The absorption at the temperature at which the clay becomes hard is about 23 per cent, and this drops to 10 per cent before the product is in danger of being melted. The average clay burns hard at cone 02 (2030° F.), and becomes viscous at cone 3 (2174° F.). These figures show a rapid fusion, and the clay should not be used in attempts to make vitrified products. (See Figs. 10 and 11.) It is suitable for common brick and hollow ware, and for fire-proofing of excellent quality, and the product will usually be cream-colored. The quality of the products is mentioned in the county descriptions of Anoka, Carlton, Carver, and Millelacs counties.

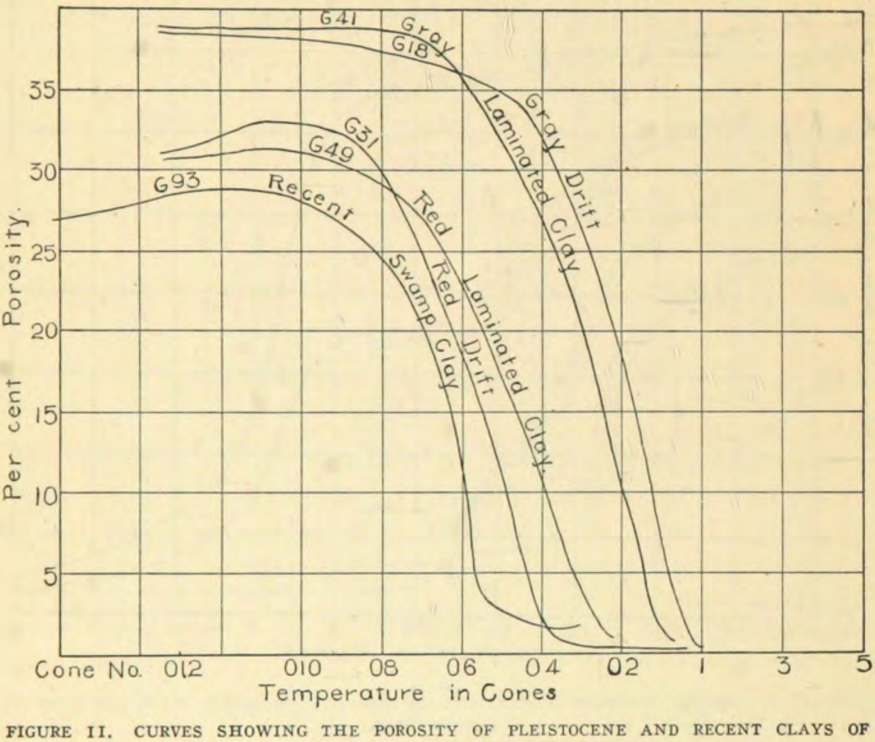


FIGURE 11. CURVES SHOWING THE POROSITY OF PLEISTOCENE AND RECENT CLAYS OF MINNESOTA AT VARIOUS TEMPERATURES.

THE RED DRIFT CLAYS

The general distribution of the red drift is along the eastern border of the State (see Plate I), from Dakota County on the south to Lake County at the north. It is most prominent in the counties which touch the border, and, where found west of these counties, it is frequently overlaid by a thin layer of gray drift. (See Plate V, A.) However, a lobe of the red drift without such a covering of gray drift extends over to the Mississippi River in Morrison County.

Summarizing the properties of the red drift, we find its plasticity not quite as great as that of the gray drift, but still perfectly satisfactory.

The materials tested have been of two types; first, the extremely pebbly and apparently unmodified drift and, second, the material accumulated at the front of the glacier as outwash—sandy rather than pebbly. These two types require slightly different treatment, but have been considered together for the following averages. (See Plate II, A.) Water required for molding is 23 per cent. The tensile strength is over 100 pounds per square inch, and is only a little lower if the clay is subjected to rapid drying. Shrinkage on drying is 5 per cent, and the fire shrinkage ranges from 2 per cent at the time the clay becomes hard to 6½ per cent by the time the clay is fully vitrified. The absorption is only 15 per cent when the clay is burned hard. The average clay begins to vitrify at cone 04 (1958° F.), and reaches viscosity at cone 3 (2174° F). It has thus a range of over 200° and can safely be burned to a vitrified brick, as is already done at Coon Creek. (See Figs. 10 and 11.) The excellence of the products of the red drift is shown by tests made by the Experimental Engineering Department of the University, on a few well-burned brick. The crushing strength was over 7,000 pounds per square inch.

GLACIAL LAKE AND RIVER CLAYS: RED LAMINATED CLAYS

Along the eastern border of the State (see Plate I), and extending a considerable distance into Wisconsin, are a series of deposits of laminated clay which have a striking red color, although in texture and relationships they seem to be similar to the gray laminated clays previously described. There can be very little doubt that their origin was dependent upon the same seasonal alternation of deposits of sand and clay brought by water from the melting ice sheet.[1]

Summarizing the properties of the glacial lake and river clays of red color, we have the following averages. Twenty-three per cent of water is required to develop the plasticity, which is only medium. The tensile strength is less than 100 pounds per square inch, but the material can safely be dried with artificial heat. The air shrinkage is 5 per cent. The clays become hard at cone 04 (1958° F.), and reach viscosity at cone 2 (2138° F.). At the temperature at which they become hard, fire shrinkage is 2 per cent, and the absorption, 16 per cent. Before the clays reach viscosity, the fire shrinkage may increase to 8 per cent. (See Figs. 10 and 11.) It is greatly to be hoped that these red burning clays may be developed to such an extent as at least partially to destroy the need of importing this type of material from Wisconsin as is now done. The extensive brick works at Menomonie, from which the Twin Cities and other parts of the State receive large quantities of red brick, make use of

[1]Berkey, C. P., Laminated clays of Grantsburg, Wis.: Jour. Geology, Vol. 13, p. 35.

laminated red clays of appearance and character similar to those found in eastern Minnesota. Another use that should be made of these clays is as a slip or glaze for semi-refractory stoneware. The red clay of the western end of Lake Superior was utilized for a short time in the town of Superior, Wisconsin, though it would seem from the bricks now to be seen in the old buildings in Superior that the clay was not burned at a sufficiently high temperature. For an analysis, see the report on Cook County. H. Ries[1] gives the following analysis of this type of red clay which appears to extend into Minnesota without change of character.

Silica	54.36
Alumina	13.40
Iron oxide	7.97
Lime	3.50
Magnesia	1.23
Potash	2.16
Soda	1.53
Titanic acid	.07
Loss on ignition	16.17
	100.39

The following analyses, most of them of Minnesota material, give evidence of the general character of the laminated clays.

Table IV. "Tripoli"

	1	2	3	4	5	6	7
Silica	77.7	77.00	82.50	70.00	77.00	77.00	77.50
Alumina	3.4	1.50	7.50	9.00	8.50	9.00	9.00
Iron oxides	3.5	7.00	....	....	....	....	......
Lime (with trace of Mg.)[1]	8.2	12.00	7.75	10.75	12.00	11.50	10.75
Water, etc.	7.2	2.50	2.25	2.75	2.50	2.50	2.75
	100.00	100.00	100.00	100.00	100.00	100.00	100.00

[1]In analyses 2-7 inclusive, lime and magnesia (trace) were determined by difference. All are quoted from Winchell, N. H., Final Rep. Geol. and Nat. Hist. Survey, Vol. 2, p. 394 et seq.

1. Tripoli, Stillwater. J. R. Eckfeldt, analyst, U. S. Mint, Phila.
2. Tripoli, Stillwater. Upper stratum of lower bed.
3. Tripoli, Stillwater. Small shaft at lower bed.
4. Tripoli, Stillwater. Dark seam through lower bed.
5. Tripoli, Stillwater. From middle of 20-foot exposure.
6. Tripoli, Stillwater. From water-line of 20-foot exposure.
7. Tripoli, Stillwater. From upper exposure on the creek.

[1]Ries, Heinrich, The clays of Wisconsin: Wisconsin Survey, Bull. No. 15, p. 168.

Table V. Red laminated clays

	1	2	3
Silica	57.79	58.52	64.76
Alumina	12.63	14.98	15.45
Iron oxide	8.88	7.92	4.86
Titanium	0.82	....	....
Magnesia	4.11	3.39	4.02
Lime	3.33	5.26	4.22
Soda	1.75	....	....
Potash	2.71	....	....
Loss on ignition	2.50	7.92	5.96
Moisture	6.10	....	....
	100.62	97.96	99.17

1. Pine County. Red laminated clay. F. F. Grout, analyst.
2. Grantsburg, Wis. Laminated clay. Mixture of layers, worked. Fairly representative. Berkey, C. P., Jour. Geology, Vol. 13, p. 38.
3. Grantsburg, Wis. From uppermost layers. Do.

LOESS

The loess is usually considered a wind-blown deposit, formed chiefly from glacial material after the ice had receded and before vegetation regained a foothold. In this State the most important deposits occur in the southeastern counties in the so-called "driftless area," as shown on Plate I. Over the uplands the loess varies from 2 to 4 feet in thickness, but in the valleys and especially on the terraces along the sides of the valleys a much greater thickness occurs. Its origin appears to be similar to that of sand dunes, but the loess is the material which, being finer grained, is carried farther than the sand. At a great many of the smaller brick plants in the State, the main deposit of clay is overlaid with loess clay and the two have been washed down the slopes together. Where the two are exposed together, they may be mixed for the manufacture of brick.

Summarizing the properties of the loess clay, we may say that they are quite uniformly as follows. The plasticity is only medium, and the water required for molding is 24 per cent. The tensile strength is not very high. The air shrinkage is 4 per cent. The fire shrinkage during vitrification increases from 2 to 7 per cent, while the absorption decreases from 21 to 6 per cent. The range of vitrification is about 200° F., from cone 02 to cone 4. An analysis is reported in the discussion of Steele County.

Tests were made on loess clay bricks by the Engineering Department of the University. The strengths were not uniform and apparently were greater in wet bricks than in dry ones. The minimum strength is 1,300 and the maximum 3,800 pounds per square inch. The average absorption is 15.6 per cent and the modulus of rupture is 582 pounds per square inch.

CLAYS OF THE RED RIVER VALLEY

The retreat of glacial ice towards the north probably occupied thousands of years, and when the ice had vacated large natural depressions like the Lake Superior basin and the valley of the Red River of the North, the ice dams across the northern sides of the basin caused the accumulation of immense lakes. The one which occupied the valley of the Red River is known as Lake Agassiz, and can be studied by its beach ridges and to some extent by the delta deposits formed by the incoming streams. But the deposits of Lake Agassiz do not seem to be as largely made up of clay as those formed in the Lake Superior basin. The drift on each side of Lake Agassiz has a moderately rolling surface. Within the area covered by the lake, the contour is much smoother and more even, but the drift shows only slight traces of stratification. Nearer the shore lines the wave action piled up beach ridges of sand and gravel, at the same time washing away the finer grained material to be deposited as clay farther from shore. But these clay sediments were evidently of small amount, and are hardly noticeable over most of the area. Very thick beds of stratified clay, however, occur in the central portion of the Red River Valley, and their position shows that they were not deposited by the waters of the lake, which must have spread much more widely over its entire area. At the present time much of the area of the stratified clay is covered by the higher flood of the Red River, and probably no portion of these stratified clays is more than 10 feet above the high water line of the Red River or its tributaries. Since the river may have been much larger about the close of the glacial epoch, it seems clear that the clays were deposited as alluvium, in part of glacial time, and in part recent. They are therefore given a separate heading, and they are prominent enough to deserve separate discussion. Their depth and the width they cover increase northward. At McCauleyville, the deposit is about 2 miles wide and about 50 feet in depth, while at Moorhead and Fargo the width is many miles and the depth is 100 feet. In general, the clay is rather sandy and contains considerable carbonaceous material. It is colored yellow by oxidation near the surface, and is highly calcareous, containing both finely disseminated lime and medium-sized pebbles and concretions. Throughout most of the valley the clays are leached to depths of from 1 to 10 feet. Over the clay is a thin layer of black loam. Only the yellow subsoil has been employed as yet for the manufacture of brick. This leached portion usually is quite free from the limestone pebbles and is less plastic and dries more safely than the lower portion. On account of the tendency to crack in drying, the lower clay is spoken of as a joint clay, and is very little used. Very little work has been done on the joint clay, though it forms much the largest portion of the whole mass. The work on preheating, referred to in Chapter II, may be suggested as a method by which this defect can be corrected with commercial success. Across the line in North Dakota, where the material is of exactly the same quality as in Minnesota, a sample of the joint clay was taken and tested by the North Dakota Geological Survey, as shown by their Fourth Biennial Report.

It contains more clay substance than the yellow clay, although considerable fine sand is still present. It takes 29.6 per cent of tempering water for the best plasticity, which is good. The tensile strength is 255 pounds, and the air shrinkage is 5.3 per cent. In burning its behavior was as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
010	Orange Pink	0.0	30.3
05	Pink	0.3	30.9
03	Pink	0.0	30.3
01	Green	(failed by cracking)	10.1

Incipient fusion occurred at cone 02, vitrification at cone 1, and viscosity at cone 2. The bricklets were all strong. This clay alone would probably be valueless, but because of its good plasticity and high binding power, it could be mixed with a sand or a sandy clay and worked by the stiff-mud process for the manufacture of common brick. Several tests have been made for the use of this clay as a paving material. In some cases, with a correct mixture, fair results are obtained.

Summarizing the properties of these clays attributed to the action of Lake Agassiz and the Red River, we have the following averages. Thirty per cent of water is required for molding. Tensile strength is 100 pounds per square inch, but somewhat reduced by rapid drying. Air shrinkage is over 6 per cent, and the fire shrinkage increases from 3 to 7 per cent during vitrification. The absorption, meanwhile, decreases from 24 to 10 per cent. Vitrification begins at cone 01 (2066° F.), and viscosity is reached at cone 4 (2210° F.). Analyses are reported in the discussion of Polk County.

Strength tests have been conducted on brick from these Lake Agassiz deposits by E. Brydone-Jack, of Winnipeg, with an average strength of 2,860 pounds per square inch, a minimum of 2,365 pounds per square inch, and a maximum of 3,760 pounds per square inch on five brick tested. Five hollow brick gave an average of 706 pounds per square inch. Surfaces of the brick were planed off and pressed between blotting paper. Bricks manufactured from the Red River silts were tested in the Engineering Laboratory of the University with the following results: Crushing strength was 1,300 pounds per square inch. The absorption was 33.3 per cent and the modulus of rupture 364 pounds per square inch.

Recent deposits

RIVER CLAYS

The chief deposits discussed under this heading are those along the Minnesota River, but the Mississippi and St. Louis rivers have also considerable deposits of this type, and many of the smaller streams contribute smaller amounts. The deposits along the Red River of the North are discussed under a separate heading.

Summarizing the properties of the alluvial clays in Minnesota, we have the following averages. The plasticity is usually rather low, and the clays are nearly always sandy. In the average case, 25 per cent of water is required for molding, and the tensile strength is about 100 pounds per square inch, even when the clay is rapidly dried. The air shrinkage will average 5 per cent and the fire shrinkage from 2 to 8 per cent during vitrification. The absorption of the brick is about 19 per cent when it first becomes very hard, which occurs about cone 02 (2030° F.). Viscosity is reached at cone 4 (2210° F.). An analysis is reported in the discussion of Goodhue County. A fairly representative sample of bricks made from alluvial clays of the Minnesota River were tested at the Engineering Laboratory of the University. The crushing strength is over 1,300 pounds per square inch, even when the bricks are wet. The absorption is 20.8 per cent. Tests of similar material by the City Building Inspector of Minneapolis gave the following figures: Wire-cut common brick, 1,497 pounds per square inch; sand-mold common brick, 1,560 pounds per square inch; wire-cut hard burned brick, 6,010 pounds per square inch.

LAKE AND SWAMP CLAYS

For the most part the recent lake clays are not expected to be of very different quality from the clays of glacial lakes of glacial time. The surface of the surrounding country still consists of the same red and gray drift, which furnished the sediments just after glacial time. Some slight differences, however, may appear, since during glacial time the melting ice furnished immense volumes of water such as are not duplicated by the more recent time. Erosion and filling of the lake beds have also had a tendency to decrease the size of the bodies of water.

Summarizing the properties of the recent lake clays, we have the following averages. The water required for molding is 26 per cent. The tensile strength is a little above 100 pounds per square inch, and is only slightly less if the clay is rapidly dried. The shrinkage on drying is 6 per cent, and the fire shrinkage ranges from 2 to 6 per cent during vitrification. The absorption at the beginning of vitrification is 15 per cent. Vitrification occurs between cone 04 and cone 2, a range of about

200°. (See Figs. 10 and 11.) Sample analyses are found in the discussion of Freeborn County. The City Building Inspector of Minneapolis has made tests on hollow brick and tile made from one of these lake clays which burn salmon at low temperature, and cream color if burned steel hard. The hollow tile gave an average of 230 pounds per square inch of crushing strength, while the hollow brick had an average strength of about 260 pounds per square inch. A test by the Engineering Department of the University on some brick made with three vertical holes, to decrease weight, showed the brick to have a strength of 3,000 pounds per square inch. The modulus of rupture was 374 pounds per square inch and the absorption was 31.4 per cent.

CHAPTER VI

DISTRIBUTION OF TYPES OF CLAY IN MINNESOTA

The types here considered are those distinguished by their physical properties. The total production of clay products of all types in Minnesota in 1910 had a value of over $1,900,000.

REFRACTORY CLAYS

The *Archean* residual clays of refractory character outcrop in the neighborhood of Redwood Falls, Redwood County, New Ulm, Brown County, and at Richmond, Stearns County. There is every indication that these clays extend under the drift from one of these localities to the other, and widely to the west to many points where well records show white clay. They may reach 50 or 100 feet in thickness. Some begin to vitrify below cone 10, but are undeformed to cone 32. Washing would improve the color and raise the melting point of most of them.

The basal *Cretaceous* clays seen from Bowlus, in Morrison County, to Redwood Falls, Redwood County, are the best refractory clays developed. As they outcrop at Richmond, Mankato, and elsewhere, they are quite certainly extensive under the drift. No doubt the well records mentioned in the preceding paragraph refer in part to these clays. The greatest thickness recorded is 18 feet at Birch Cooley, near Morton, Renville County. The best material is that near Redwood Falls. That farther north is more ferruginous, but nevertheless refractory.

The higher Cretaceous clays at several points in Brown County, and from there to Ottawa in Le Sueur County, are also highly refractory. An attempt was once made to use the clay at the latter place, but the plant is now idle. Conditions seem favorable for its success. Along the Cottonwood River in Brown County, notably in Sec. 36, T. 110 N., R. 31 W., the clay is of especially high quality. Much of the country between and around these places may be worth more careful prospecting than it has received.

SEMI-REFRACTORY CLAYS

VITRIFYING CLAYS

Cretaceous shales are the only ones in this class, and those mined for the stoneware and sewer pipe works at Red Wing are the best known. Their vitrifying behavior is exceptionally good, but they fuse at such low temperatures as to leave them very near the non-refractory class. The deposits which are worked at Clay Bank and Belle Chester are disturbed and apparently transported remnants of a larger formation which must have existed some distance northwest. If the main body still exists, it is covered with drift and is not known. Careful observations should be made and records kept of all drilling in the region. The deposit at Belle Chester was discovered a relatively short time ago by drilling where the drift gave evidence of some included clay brought from the same direction as that at Clay Bank. Drilling should be continued in both directions, though it is likely that the main sources of the clay may now be more deeply covered with drift than the transported masses. These clays are the most valuable yet developed in the State and with new discoveries may continue to be the most valuable.

West from these points the Cretaceous shales in many places are non-refractory, but the character of two deposits, one at Austin, Mower County, and one near Essig in Brown County, shows that the conditions for the development of the type were widespread and there is every reason to expect similar clays to be discovered here and there under the drift over any part of the counties between. The clay at Austin is now being explored by drilling. That near Essig is excellent, but at present somewhat inaccessible and of uncertain quantity.

CLAYS THAT MELT SUDDENLY

The *Huronian* residual clays near Bowlus in Morrison County, and the Huronian paint rock on the Mesabi Range are to be classed here.

NON-REFRACTORY CLAYS

VITRIFYING CLAYS

Aside from the smaller formations of no importance as clays, the great formations yielding this type of clays are the Decorah shales, the Cretaceous shales, and the Pleistocene red drift. These without exception have a good range of vitrification. Recent lake clays also show a fairly good range. Some other Pleistocene and Recent clays may have a good range, but most of them have not. The vitrified brick and drain tile produced in Minnesota in 1910 had a value of nearly $250,000.

The *Huronian slates,* when mixed with a small amount of red drift clay, will show a range of vitrification which makes it possible to burn them to excellent fancy brick. They outcrop conveniently to Duluth at Carlton, Thompson, and up and down the St. Louis River.

The shales of the great red sandstone of Keweenawan or Cambrian age outcrop so rarely and are so thin that they are not likely to be developed, though the quality seems to be excellent.

The *Decorah shale* of the Ordovician is uniformly of excellent quality. The ground samples without exception had a range of over 200° F. during vitrification, and some had 400° F. This is somewhat surprising as the temperature of fusion is low and the shales contain limestone impurities. The distribution of these shales has been carefully mapped. (See Plate I, and Figs. 12, 13, and 14.) The western and southern limits shown are not the end of the shales, but approximately where they dip under Cretaceous or Devonian rocks and are inaccessible. Even in the area mapped, the drift cover may be so great as to render some parts of no value, but the main border is almost everywhere well situated for development. At Faribault, Rochester, and Cannon Falls the conditions seem favorable.

Devonian shales of this character are thin and outcrop in but few places.

The *Cretaceous shales* are known to underlie the surface over most of the southwestern part of the State, though deeply concealed by drift except here and there. These extend as far east as Koochiching, Itasca, Stearns, and Goodhue counties. All vitrify safely.

Associated with the semi-refractory clays at the Red Wing pits are some non-refractory clays with a noteworthy range of vitrification. Still less refractory clays are found a little west in Mower County at Austin, and along the line between Mower and Fillmore counties. The most numerous outcrops of such shales are near New Ulm, where a few beds of semi-refractory shales also occur. Along the bluffs of the Minnesota River and the Cottonwood River from New Ulm to Springfield, the outcrops are so large and so numerous as to indicate large bodies of shale, which will no doubt be developed. The overburden may delay the work at some of them, but others are not covered, and, like that at Springfield, would make excellent vitrified ware. The color of the product of some is much lighter than that of others, and in well-vitrified samples ranges from buff to reddish brown.

A large body of similar shale outcrops at several points near Richmond, Stearns County, and might easily be developed. The presence of a thin lignite bed has diverted attention from the clay to prospects of coal.

Similar clays are reported in well records in the southwestern counties and their character can be judged by a sample from Brown Valley, Traverse County, which burns red, and has an excellent range of vitrification.

The Pleistocene red drift has been used with remarkably fine results at Coon Creek, north of Minneapolis, and with less favorable results at Forest Lake, Barnum, and Wahkon. The outwash of the red drift has been used at Rush City, West St. Paul, and Burtrum. At all these places its range of vitrification makes it possible to get a hard, well-burned product. The distribution of such drift is shown on the map in a general way and the fact that the red drift at Coon Creek is covered with gray drift, shows that this is not an insurmountable difficulty. Much of the red drift is too sandy, but where pebbles and sand are not too abundant, it is capable of much more development than it has received. All has a satisfactory range of vitrification.

The map makes no distinction between the red drift from the north and that from the northeast. The latter (mostly in Pine and Carlton counties) is equally good when largely composed of clay. The water-laid drift in Carlton County is excellent, but requires some sand for molding.

Gray drift is rarely suitable for hard brick until pebbles have been removed from it.

Gray laminated clays are also rarely vitrified with safety. A few samples were found to burn red (instead of the common cream), and have a fairly good range of vitrification. Notable among these are the clays near Aitkin and one or two which were much weathered so that the lime may have been leached out.

Loess of the southeastern counties is in a few cases of satisfactory range, but cannot be recommended for vitrified brick.

Clays occupying recent lakes and swamps, in areas of both the gray drift and the red drift, have a satisfactory range for vitrification. In any part of the State the clays of swamps or lake shores are worthy of attention, especially if easily drained.

CLAYS THAT MELT SUDDENLY

These clays are good only for common brick, fire-proofing, or slip glazing. The brick produced in Minnesota in 1910 had a value of over a million dollars; the fire-proofing had a value of $93,731.00.

Besides the minor formations, too thin to be of value, this class includes about three-fourths of the gray drift clays and about seven-eighths of the gray laminated clays and Lake Agassiz and river silts. A few of the silts which burn red have a better range of vitrification. All the red laminated clays are of this class. The loess and the river alluvium are partly of this type.

The area of the *gray drift* is shown on the map. It is not to be expected that pebbly clay in this area will make good common brick unless treated by some process such as that used at Hutchinson and Jackson. Then it may make not only brick, but good drain tile. Its range is increased so that it is a safely vitrifying clay.

The gray laminated clays occur within the area of gray drift, as mapped, and in a few cases outside that area, where a stream crossed from the gray drift to the red. As examples, there are gray clays along the Mississippi River from Brainerd to St. Cloud, where red drift is the main deposit. Another area in which gray clays lie in a region of red drift is at Wrenshall and vicinity.

Red laminated clays occur mostly along the St. Croix River, but are known in St. Paul, near the Mississippi River, and in Floodwood, of St. Louis County, near the St. Louis River, and are probably extensive in the red drift area. Several are very fusible and will make an excellent glaze at cone 7.

The loess is most prominent in southeastern Minnesota, but is no doubt widespread over the southwest too, though so mixed with surface wash as not to be classed separately. It is good only for common brick.

The deposits of Lake Agassiz and Red River occupy a strip along the river from Traverse County north to the state line, increasing to the north both in width and depth.

Recent alluvium of the rivers (but not of the lakes and swamps) is largely of this type. Many deposits of the Minnesota and some of the Mississippi and St. Louis rivers yield common brick.

CHAPTER VII

THE CLAYS OF MINNESOTA BY COUNTIES

AITKIN COUNTY

Types of clay, 2. Recent......................Alluvium
1. Pleistocene.................b) Gray lake clay
a) Red drift

Red sandy drift covers the southern portion and gray drift the northern portion of this county. Reports of clay along the Soo Railway east of Aitkin may be worth investigating.

At the town of Aitkin there apparently existed a large depression into which the Mississippi River and its glacial predecessor have brought great quantities of fine-grained clay. The surface here for many miles is practically a flat swamp and for a considerable distance on either side of the Mississippi is subject to an occasional flood. The Mississippi and its tributaries have cut their channels only a few feet below the general level, but at low water as much as 8 feet of laminated clay may be seen in these shallow gorges. The clays now exposed are rather sandy, yellowish gray in color, and have probably been formed by the recent river. Well records show that the deposit extends to great depth with only an occasional sandy layer. In Sec. 24, at the northeast edge of town, a brick yard was built 26 years ago and rebuilt in 1900, but the product has been small. The pit was located so close to the banks of the river that probably a large proportion of the clay used was alluvium, but the main part of the deposit here described must be classed as a lake deposit because of its great extent in all directions. The former shore lines can be traced by beach ridges, one of which passes directly through the town of Aitkin. Several samples of the clay were taken. The clays slake at once and show only a medium amount of plasticity. They require 22 per cent of water for molding and have an air shrinkage of 4 per cent. Their tensile strength is about 100 pounds per square inch in the average case, and they could be safely dried with artificial heat.

Burning tests resulted as follows:

Cone. No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Red	0.5	18
02	Red	3.0	16
1	Red	7.0	7
3	Red	8.0	5
5	Red	......	......

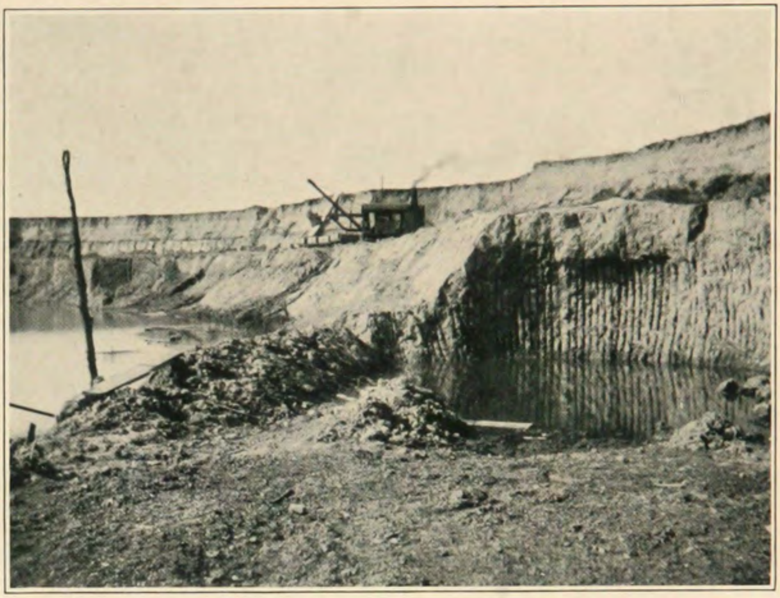
The clay becomes too hard to scratch with a knife at cone 02 (2030° F.), and does not become viscous at cone 5 (2246° F.). These tests show an excellent quality of clay with a range of vitrification considerably over 200°. One sample taken from the eastern end of these lake deposits along Rice River showed a rather lower tensile strength and a lower temperature of fusion. This clay reached viscosity at cone 01 (2066° F.). It should be safe to burn these clays thoroughly hard and perhaps to vitrification. So far only common brick have been made from them, but their great extent and accessibility should make them the subject of further experiment. The fact that they are gray laminated clays, but burn to a red color, would indicate either that the upper portion of the deposit has been greatly leached of lime, or that the red drift has contributed largely to their formation.

ANOKA COUNTY

Types of clay, Pleistocene...............c) Gray lake and river clays
b) Red drift
a) Gray drift

At the lower end of the southern panhandle of the county, where it adjoins northeast Minneapolis, there is a very extensive deposit of gray clays. This extends along both banks of the river well down into the city of Minneapolis, but, on account of the value of the property within the city limits, there is an increasing tendency to crowd the brick-making industries north into Anoka County and outside the city limits in North Minneapolis. The detailed description of the clay will, therefore, be given here at the beginning of the chapter in connection with Anoka County rather than later in the discussion of Hennepin County.

The bed rock formations along the Mississippi River north of Minneapolis are the St. Peter sandstone and overlying it in the bluff, the Platteville limestone. Over this the hillsides show first the red drift, and above that the gray drift. Both the drift and the bed rock have evidently been eroded by the glacial Mississippi River, resulting in the formation of a wide channel, which, during glacial times and probably continuously since then, has been the site of the deposition of these gray laminated clays. The relations of the different formations at this point are illustrated in Fig. 7. The entire mass of stratified clay undulates at angles of 10 to 20 degrees. The clay is essentially the same from top to bottom, having been opened to a depth of over 30 feet at several brick yards. The curious internal structure seems to have been caused by eddying motions in the water which came down the river periodically. Some of the layers are singularly contorted in their finer laminations. (See Plate



A. RED DRIFT BELOW GRAY DRIFT AT COON CREEK. THE STEAM SHOVEL IS LOADING GRAY DRIFT ON DUMP CARS. IN THE FOREGROUND ARE SEEN THE MARKS OF TEETH OF THE STEAM SHOVEL ON THE RED DRIFT CLAY, WHICH IS USED.

B. GRAY LAMINATED CLAY, USED IN NORTH MINNEAPOLIS.

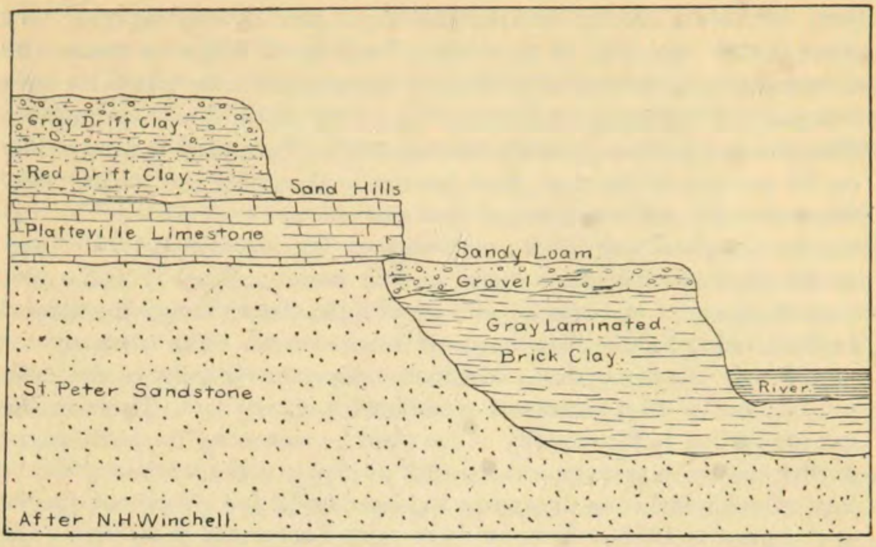


FIGURE 7. SECTION SHOWING THE OCCURRENCE OF GRAY LAMINATED CLAY IN NORTH MINNEAPOLIS.

V, B.) The sandiness of the deposit varies erratically, and most of the pits opened are said to be pockety. Although it is stated above that the clay is uniform, such uniformity is limited to the larger features, and the clay products manufactured are uniform only if the clay is mixed from several parts of a reasonably large exposure. When this is done, the products are excellent. The clay slakes at once and is highly plastic, requiring 24 per cent of water for molding. Its tensile strength is nearly 200 pounds per square inch and its air shrinkage is about 4 per cent. As tested by the U. S. Bureau of Standards, it behaves as follows: It works well in the auger machine without lamination. Burned colors are buff to greenish at higher temperatures. The porosity is over 30 per cent up to cone 05, and fusion occurs suddenly with a decrease in porosity to 1.6 per cent, at cone 02. It is to be recommended for common brick and fireproofing.

Work began in 1879, and since then eleven plants have been built and have been actively at work. Most of them produce cream-colored brick, for which there is a considerable demand in the Twin Cities for backing of brick walls and for interior work generally. At most of the plants the bricks are not burned very hard, but serve the ordinary purposes very well. Most of the plants have a capacity of approximately 40,000 bricks per day, and operate through the whole season until frost. Probably nine-tenths of the brick are burned in large scove kilns. To effect economy in labor and fuel the Minneapolis Brick and Tile Company installed a continuous kiln with a gas producer for firing at their plant on the west side of the river. Thus far it is not so much more economical as to be used in preference to the scove kilns which the same company also operates on the east side of the river. The Northwestern Fire-proofing Company, which has the most northern plant now operating on the east side of the river, have practically abandoned the production of common brick and have devoted their energies and their plant to the production of hollow ware, with great success. The proximity of the Minneapolis saw mills has been a factor in their success. They furnish a convenient supply of sawdust for mixing with the clay to render the finished product much lighter than it would otherwise be. The company has now a stock pile of sawdust and a thoroughly explored bank of clay sufficient to assure them successful operation for many years. They are frequently adding to the capacity of the plant by increasing the facilities for drying and by so arranging their stock of clay that the machinery can be kept running earlier in the spring and later in the fall. Work was begun at this plant in 1875, and shows every sign of continued prosperity. The Minneapolis Brick and Tile Company also produce hollow ware in their continuous kilns. The quality of the products made from this clay is indicated by the following tests. The Minneapolis Building Inspector reports the average strength of 10 bricks from one plant as 2,968 pounds per square inch, with a minimum of 1,600 pounds and a maximum occurring in a brick from the center of the kiln, of 5,080 pounds per square inch. Three other series of tests on bricks from this deposit gave an average strength of 1,560 pounds per square inch, with a minimum of 631 and a maximum of 2,770 pounds per square inch. A series of 5 bricks from one plant gave an average strength of 2,588 pounds per square inch. The general average of all the brick tested at this office from the North Minneapolis deposits is over 2,000 pounds per square inch. One test by the Minneapolis Building Inspector on a hollow tile about 4 x 8 x 17 inches, with 6 one-inch openings through it lengthwise, gave a strength of 604 pounds per square inch.

The following partial analyses of the clay are available:

Analyses of Gray Laminated Clays of Minneapolis

	1	2
Silica	50.65	54.17
Alumina	10.25	16.67
Iron oxide	4.00	8.06
Titanium oxide	0.52	.....
Magnesia	4.68	.....
Lime	10.65	.....
Soda	1.44	.....
Potash	1.96	.....
Moisture	1.20	.....
Ignition	14.40	.....
	99.75	.....

1. Pit of Minneapolis Brick and Tile Co., west of the river, F. F. Grout, analyst.
2. Pit east of river. Analysis reported by C. P. Berkey.

The Experimental Engineering Department of the University report the strength of the North Minneapolis brick as follows: Five dry brick had an average crushing strength of 1,940 pounds per square inch and wet brick were only slightly weaker. The modulus of rupture is 411, and the absorption 29.7 per cent. There is some variation in the product at different yards.

While it has been proved in actual practice that these clays are capable of producing excellent common brick and about the best fire-proofing of any clays in the Northwest, and in years past have even been used for pottery, it is recommended that attempts be made to mix this clay with some of the other clays available in the neighborhood in the attempt to produce vitrified ware which will stand burning to a harder product. Such products are greatly in demand in the Twin Cities and are now imported from other states.

The Minnesota Paving Brick Company has an extensive plant at Coon Creek, where the red drift is known to be 40 feet thick and is explored over 200 acres with an overburden of 20 feet of gray drift. (See Plate V, A.) As dug from the ground, it contains a small proportion of pebbles and bowlders, but these are not as numerous as in the average of the red drift throughout the State. None of the pebbles consist of limestone except in the overlying gray drift, which is discarded. The pebbles which do occur in the drift would be quite sufficient to ruin it for ceramic purposes unless crushed or removed. At the Coon Creek plant all the clay dug is put through a double series of conical rolls by which a large proportion of the pebbles are removed, and the rest are crushed to a size that renders them practically harmless. A sample of the clay was taken from material passed through these rolls. The clay slakes quite promptly and shows a fairly high plasticity, requiring 24 per cent of water for molding. Its shrinkage is 5 per cent and its tensile strength is nearly 100 pounds per square inch, though somewhat less if rapidly dried. As tested by the U. S. Bureau of Standards, it behaves satisfactorily on vitrification, the porosity decreases from 32 per cent to .4 per cent before melting and is less than 5 per cent through a range of about 100° F. The color changes from red to chocolate at vitrification.

The Coon Creek company has a plant making use of a steam shovel and 6 large down-draft kilns, with a total capacity of about 40,000 brick per day. The product of the plant is largely used by the Great Northern Railway in the construction of their station buildings and the paving for their station platforms. Some well-vitrified brick are roughened in imitation of klinker brick for fancy building material and some kept smooth for paving. At Minot, North Dakota, a platform was built partly with these brick and partly with the famous Purington brick, from Galesburg, Illinois. The practical test of service in this platform is very much in favor of the Coon Creek product, for such purposes. However, for the harder use in paving city streets, the Coon Creek brick do not seem to have become especially popular. It is to be hoped that if there is some slight defect which makes them undesirable for this purpose, it can soon be overcome. The City Engineer of Minneapolis has reported comparative tests of the Coon Creek brick with the cobblestone paving produced in Minnesota, and the various types of paving brick which are now imported into the State. The average breaking load of Coon Creek brick was 16,000 pounds, which was the maximum of those tested. The modulus of rupture was over 4,000 pounds, and greater than that of any other tested. The average crushing load was over 17,900 pounds per square inch, which is greater than that of any other tested. The per cent of absorption was 0.0, the per cent of abrasion was 7.18, which was as good as the best of the imported paving brick.

The gray drift of the county is of the usual type and cannot compete with the other clays.

BECKER COUNTY

Types of clay, 2. Recent ....Lake clay
1. Pleistocene ....Gray drift

Along the Soo Railroad, about a mile south of the station at Detroit, there is a deposit of gray drift which is massive, full of pebbles, and very sticky, though not very plastic. The clay slakes in 1 minute and requires 30 per cent of water for molding. Its tensile strength is about 50 pounds per square inch even when rapidly dried. A good plant for the production of brick and tile was erected at this deposit, but the difficulty of using a clay containing so many limestone pebbles caused the failure of the undertaking and a loss of considerable money. Unsuccessful attempts were made at crushing and at washing to obviate the difficulty.

In the neighborhood of White Earth and Ogema are several swamps and lakes containing clays which were used to make brick for the construction of the government industrial school for the Indians. Very attractive and durable bricks were made, though a few lime pebbles are visible. If the market warrants it, there are no doubt numerous deposits of such clay in this neighborhood worthy of exploitation.

BELTRAMI COUNTY

Types of clay, 2. Recent ....Lake and river clays
1. Pleistocene ....b) Silt of Red River Valley
a) Gray drift

The gray drift is thick over most of the county, and in part of the area the silts of the Red River Valley have smoothed the topography by filling up the depressions of the drift sheet under deposits which increase in thickness to the northwest. Both the silts and drift require the removal of limestone pebbles to yield workable clay.

At South Bemidji, in a very favorable situation as regards shipping facilities, the south shore of a lake which is formed by the expansion of a river, contains blue and yellow clay of a common laminated type. It has been used at a medium-sized brick yard at South Bemidji for common brick. The deposit covers many acres and is exposed to a depth of 20 feet, but is covered more or less deeply with very sandy overburden. At the present location, from 4 to 8 feet of sand are being removed. Some sand is occasionally used in tempering the clay. The brick now visible in the kilns look as if an attempt had been made to mix the yellow clay, which is the chief body of the clay exposed, with the underlying blue clay. The latter appears to have been very plastic and, as it is dug in a moist, but solid condition, it did not mix well and a most decided auger structure is apparent. The brick are badly cracked. Possibly a more thorough pugging before they are transferred to the auger machine would remedy this defect. Otherwise it is recommended that the two kinds of clay be used separately. It should be possible to make excellent products from this deposit.

North of Bemidji, the shores of Bemidji Lake are composed of a more recent lake deposit which has been left exposed by a gradual lowering of the lake level as its outlet has been eroded. This particular deposit is highly calcareous, and it was investigated to ascertain whether it is suitable for cement. A partial analysis by F. F. Grout is as follows:

Insoluble, iron and aluminum oxides	65.90
Magnesia	5.10
Lime	12.20

The lime and magnesia existing in the form of carbonates, make up about one-third of the material, but are not sufficient to justify its use for cement, especially as the magnesia is too large a proportion of the whole. The material would probably burn to a cream brick.

BENTON COUNTY

Types of clay, 1. Pleistocene ....b) Gray lake and river clay
a) Red drift

Northeast of Sauk Rapids, along Elk River, grayish yellow laminated clays outcrop here and there, and these were once used for making brick.

The location is unfavorable for a large plant. Other deposits may be found along the Elk or Mississippi rivers, but most of the county exhibits only red drift and outwash.

BIGSTONE COUNTY

In Bigstone County, the only clays known are in the gray drift. These are of the usual type and require cleansing before use. Archean residual material is found at 250 feet in a well near Johnson.

BLUE EARTH COUNTY

Types of clay,	3.	Recent................	Alluvium and swamp clays
	2.	Pleistocene	Gray drift
	1.	Cretaceous clays	

Five miles south of Mankato, in Sec. 35, the Cretaceous overlies the Jordan sandstone and underlies the drift along the banks of the Le Sueur River. The drift is from 10 to 20 feet thick, the Cretaceous from 30 to 40 feet thick. The crumpled condition of the Cretaceous deposits and the irregularly lenticular form of the clay lenses which occur in them indicate the probability that the whole series was distorted by the crowding of the glacial ice. Samples were taken from some of the smaller clay lenses, which are rarely over a foot thick, but were found outcropping for several hundred yards along the cliffs. The clay is very fine grained and chalky, though stained with iron in a few places. It does not slake when dropped into water. It is extremely lean and requires 27 per cent of water for molding. Its air shrinkage is about 1 per cent. At about cone 3 (2174° F.), it becomes so hard that it cannot be scratched with a knife. It is highly refractory and will stand a temperature of cone 33 (3254° F.) without deformation. It remains nearly white in color, varying from tints of buff to creamy brown. About 20 years ago the Pauline Pottery Company, of Chicago, tested the clay for the manufacture of fancy pottery. Mr. Joseph Kern, of Mankato, who owns the property, has some vases which were made in the experiment, which are very beautiful but very fragile. The phase which appears concretionary has 47.4 per cent silica, and 14.5 per cent water. Other outcrops near Mankato are believed to be Cretaceous shales.

Above the basal Cretaceous clays already described are a great many outcrops of alternating shale and sandstone with an occasional ferruginous craggy conglomerate. These various occurrences have been described by Warren Upham,[1] but most of the clay beds are rather thin and their extent is not well determined. (See Figs. 5 and 6.) Their character is indicated

[1] Upham, Warren, Minn. Geol. and Nat. Hist. Survey, Vol. 1, pp. 432-9.

by a sample taken in Le Sueur County discussed below. They are worthy of further exploration. Analyses are given in Table III, page 45.

The gray drift covers most of the county and shows the common characters. A sample was taken just southwest of Lake Crystal on the Omaha Railroad, where the deposit, of considerable size, is known to be 30 feet thick. Gravel was not as abundant at this point as in the average of the gray drift. After crushing the clay to 40-mesh it was found to have the following properties. Its plasticity was low, but required 24 per cent of water for molding. The tensile strength was over 150 pounds per square inch, even when the clay is rapidly dried. The shrinkage was 4½ per cent. Burned at the Minnesota School of Mines Experiment Station, it gave the following results:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
04	Salmon	......	......
03	Salmon	1	20
02	Salmon	1	19
1	Salmon	3	14
2	Brown	6	10
4	Brown	......	......

Up to the temperature of cone 03 (2000° F.) the particles of lime remaining in the burned brick cause its rapid disintegration on exposure to the air. The clay became too hard to scratch with a knife at this temperature and became viscous at cone 4 (2200° F.). Three plants have been started to make use of the drift in this neighborhood. None of them is now at work. Success would depend not only on market conditions, but on some method of removing limestone pebbles.

At Garden City and vicinity similar gray drift contains more than the usual proportion of limestone pebbles.

Five miles southwest of Mankato is a deposit on the farms of Mr. Joseph Kern and Mr. Frank Pearson, which extends over several acres to a depth of several feet. Near the surface the lime pebbles of the drift are less abundant than in the average of the gray drift. The clay slakes in 3 minutes and is highly plastic, requiring 23 per cent of water for molding, and showing a shrinkage of 5 per cent on drying. Its tensile strength was 100 pounds, but rapid drying affected this quite seriously. Burning tests resulted as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
04	Salmon	1.0	15
03	Salmon	1.5	14
01	Red	2.0	13
1	Red	5.0	10
2	Red	6.0	4
5	Brown	......	......

The clay becomes too hard to be scratched with a knife at cone 03 (1994° F.), and reaches viscosity at about cone 3 (2174° F.). If the economic conditions are found favorable, this clay is certainly capable of yielding a good grade of brick and tile. This overlies the pit formerly worked for Cretaceous clay of refractory grade and about worked out.

At Mapleton the entire region is covered with the common type of gray drift, with the average number of pebbles.

Near Rappidan, along the Milwaukee Railroad, near a bridge across the Le Sueur River, the whole country is covered with the usual type of gray drift. The upper part of the drift has been leached and is somewhat better clay than the main body. The clay slakes in 2 minutes, is highly plastic, requires 22 per cent of water for molding, and shrinks less than 5 per cent on drying. Its tensile strength is nearly 200 pounds per square inch even when rapidly dried. Burning tests resulted as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Salmon	1	22
01	Salmon	4	18
2	Brown	7	8
4	Brown	......	......

The clay becomes too hard to be scratched with a knife at cone 06 (1886° F.), and viscous at cone 3 (2174° F.). It might be used without as extensive a treatment for the removal of the lime pebbles as is undertaken at Hutchinson. The market conditions are favorable, though throughout the southern part of the State there is competition from the plants in Iowa.

Recent alluvium is found at many points along the Minnesota River and some of its tributaries, such as the Le Sueur. Two and a half miles west of Mankato, a brick yard is in operation on alluvium of the Minnesota River, of which from 6 to 12 feet is workable and extends along the river in a flood plain of very great extent. It is typical of the material between Chaska and New Ulm and even beyond. The clay slakes at once and its plasticity is very low. It requires 22 per cent of water for molding and shrinks 4 per cent on drying. Its tensile strength is 175 pounds per square inch, whether it is slowly or rapidly dried. It is rather sandy, and some care has to be used to exclude even the coarse gravel which occurs in irregular layers. As burned at the Minnesota School of Mines Experiment Station it gave the following results:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Salmon	0.0	24
02	Salmon	0.5	22
1	Brown	7.0	10
3	Brown	8.0	6
5	Brown	......	......

The clay burns steel hard at cone 02 (2030° F.), and is near viscosity at cone 5 (2246° F.). The plant is making an excellent quality of common red brick by a soft-mud process at the rate of about 4 million per season. Another favorable place for the development of this alluvium near Mankato is about 40 rods north of the city limits, along the Omaha Road, where the river basin extends to a width of 3 or 4 miles.

Three miles from the station of St. Clair, on the south bank of the Le Sueur River, is a swamp of 40 acres or more, which has been drained by a ditch. It exposes a clay about 15 feet in thickness, the upper part of which is yellow and the lower blue-gray. A few feet of peat overlies the clay in part of the swamp. The clay seems to be exceedingly pure. It slakes in 6 minutes and is highly plastic, requiring 30 per cent of water for molding. Its tensile strength is about 80 pounds per square inch and its air shrinkage is 8 per cent. In burning it becomes hard and is salmon-colored at cone 06 (1886° F.). Its absorption at this temperature is 16 per cent. There is enough organic matter present so that, if rapidly heated, the bricks would swell and crack and develop black cores, but, if slowly heated and thoroughly oxidized, good red brick can be produced, and viscosity is not reached below cone 1 (2100° F.). All conditions seem to be favorable for the manufacture of brick and tile, except that the deposit is located about a mile from the railroad.

Near Good Thunder in this county about a half mile south of the station, is a deposit in a swamp covering many acres, which had been worked up to 1904 for many years. The clay is quite free from limestone pebbles, and the brick made from it have stood the test of service for nearly 30 years in some of the buildings in the town. An analysis was made by F. F. Grout for Dr. J. T. Schlesselman some years ago.

Surface clay

Silica	70.29
Iron and aluminum oxides	18.71
Magnesia	1.35
Lime	2.02
Soda	0.56
Potash	1.87
Moisture	2.15
Ignition	3.60

This is probably fairly characteristic of the bog deposits throughout much of the State. They may contain constituents of the wind-blown loess, but are largely made up of the wash from the neighboring hillsides.

The humic acids developed in the bog tend locally to leach out the soluble lime and iron, but generally enough iron is left so that the clay will burn red.

BROWN COUNTY

Types of clay,	4. Recent	Alluvium
	3. Pleistocene	Gray drift
	2. Cretaceous	b) Shales
		a) Basal clays
	1. Archean	Residual clay

Mr. Oliver Bowles, who made a study of this county, contributes the following data:

The only working plants in Brown County are at Springfield and New Ulm. The plant at Springfield is supplied from an extensive bed of laminated Cretaceous shale, while the plant at New Ulm employs the extensive brown and yellow clays deposited along the Minnesota River, sometimes adding some gray laminated clay from the bluffs near by. The gray drift over most of the county contains many pebbles, chiefly of limestone. Since clays of much better quality exist in this county, the plants which used it are abandoned and no further development of the gray drift is to be recommended.

In Sec. 36, T. 110 N., R. 31 W., along the banks of the Cottonwood River, near water level, is an exposure of about 10 feet of a white clay which extends several feet below the bed of the river, but its extent has not been fully determined. Outcrops were seen for a distance of one-half mile along the banks. A large part of the clay is very gritty with coarse angular quartz. The mixture of this quartz with the clay gives the appearance of a granitoid texture and indicates that this is residual or colluvial. Some parts of the outcrop show very little of this quartz, and some are highly colored in variegated tints, but by far the largest part of the formation is clear white in color. This was recently described by F. W. Sardeson.[1] At the best outcrop the following section was recorded.

Gray drift	40 feet
Cretaceous clay and sand, disturbed	8 feet
Cretaceous white gritty clay	12 feet
Archean rotted granite	4 feet to water level

[1]Sardeson, F. W., The Redstone Quartzite: Bul. Geol. Soc. Am., Vol. 19, p. 223.

The clay slakes in 3 minutes, is highly plastic, and requires only 19 per cent of water for molding. Its tensile strength is not much over 70 pounds per square inch. Its air shrinkage is 5 per cent. As burned by the Minnesota School of Mines Experiment Station it gives the following results:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Light red	1	15
1	Red	1	15
4	Red	2	13
5	Red	......	......
13	Light brown	......	......

The clay becomes too hard to be scratched with a knife at cone 06 (1886° F.), and, while thoroughly vitrified, it is still undeformed at cone 13 (2534° F.). This sample, representing as nearly as could be judged the average of the formation, contained about 50 per cent of sand too coarse to pass a 60-mesh sieve. Over 30 per cent was fine enough to pass the 200-mesh sieve. If this is at all suitable for the production of high-grade chinaware, it should be possible to make a commercial success of a washing process to remove the quartz and some of the coloring matter.

In Sec. 36, T. 110 N., R. 30 W., is another outcrop of so-called pottery clay. This is part of the Big Cottonwood formation described by Sardeson.[1] It is not particularly well situated for shipping. It outcrops about two miles from where the Minneapolis and St. Louis Railroad leaves New Ulm going south. The outcrop rises 6 or 7 feet above water level in the Cottonwood River and extends an unknown distance below water. Twenty or thirty acres appear to be underlaid with the material. As tested by the Bureau of Standards at Pittsburgh, the properties are as follows: The plasticity was satisfactory for working in an auger machine with 17 per cent of water. The drying shrinkage was 5 per cent. Burned colors were fairly white, but iron granules could be seen. The clay softens at cone 31½ (3200° F.). Machine-made brick had a tendency to check in burning, but this was not true of the hand-mold brick. This is an excellent refractory clay, and should be of value.

Mr. Aufderheide, of the brick plant at New Ulm, has made some fire brick of the material, described as from Sec. 36, which was refractory, but did not show a satisfactory strength after being repeatedly heated and cooled. No other attempts have been made to use these clays.

In the neighborhood of New Ulm, and across the river in Sibley and Nicollet counties, there are a great many outcrops which are

[1]Op. cit. p. 231.

worthy of more attention than they have received. In the city limits of New Ulm, in the southeast part of town, a pottery was established some 30 years ago and obtained its material from a bed from 4 to 8 feet thick of uncertain extent, but said to exist under the center of town with no more than 10 or 12 feet overburden. The clay slakes in 2 minutes, is highly plastic, and requires 20 per cent of water for molding. It has a tensile strength of 200 pounds per square inch and can safely be dried with artificial heat. The air shrinkage is less than 4 per cent. Burning tests gave the following results:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Cream	0.7	14
03	Buff	1.0	......
1	Buff	1.4	12
5	Buff	......	......
12	Light gray	......	......

The clay becomes hard at cone 03 (1994° F.), and, while well vitrified, it does not seem to be near viscosity at cone 12. This deposit should be carefully studied to determine its extent.

Near the south side of town, near the Northwestern Railroad crossing over the Cottonwood River, shales occur to a depth of 40 feet extending over an unknown area, probably very great. The lower main portion is a rather soft gray clay, very favorably situated for development. It slakes very slowly, but is highly plastic, requiring 29 per cent of water for molding. Its tensile strength is 150 pounds per square inch, but rapid drying lowered this very materially. Its air shrinkage is 10 per cent. As burned by the Minnesota School of Mines Experiment Station, it gave the following results:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Salmon	2	12.0
02	Salmon	4	7.0
01	Brown	5	3.0
2	Brown	5	2.6

The clay becomes too hard to be scratched with a knife at cone 05 (1922° F.), and is viscous above cone 2 (2138° F.). This is one of the most promising bodies of Cretaceous clay that have been investigated. Most of it is gray in color, and it can be traced through the various hills in the neighborhood. Boring and wells have revealed the fact that the clay extends over considerable territory where it is concealed by later deposits. The upper portion of the deposit is red and evidently calcareous, possibly contaminated with gray drift and possibly with Cretaceous limestone. It is certainly much less valuable clay, but this poor clay is thin and there is 40 feet of the gray clay below. The extent of such clay is shown by an outcrop of similar character along the Cottonwood River in Sec. 31, two miles west of town, though at this point the drift cover is heavy and less than 10 feet are exposed.

Across the road from the New Ulm Farmers' Elevator on a property now used as a city park, is a third outcrop of shale which is red above and blue-gray below, and which can be followed along the bluff for considerable distance. Economic conditions are excellent and, if material underlying the less valuable property is similar in character, there should be room for some industrial development. The slaking and plasticity are about the same as in the other samples. The air shrinkage is 8 per cent. The clay burns salmon-colored and becomes hard at cone 05 (1922° F.). At cone 2 (2138° F.) it has become greenish gray and is at the point of viscosity.

An exposure much less favorably situated occurs near the brewery of the A. Schell Brewing Company. The physical properties of this material are not as good as those above reported.

Three or four miles south of Essig, on the Northwestern Railroad, an outcrop occurs along the Cottonwood River almost continuously for a mile, showing 6 feet above water level and existing for unknown depths below. It is white to gray and very plastic. The outcrops are not perfectly continuous and, as there seems to be a difference between the white clay and the gray which is associated with it, it may be that the white clay exists mostly in pockets. Both the white and gray clay slake in a few minutes and are highly plastic, requiring 23 per cent of water for molding. The tensile strength is well above 100 pounds per square inch, even after rapid drying. The air shrinkage is about 7 per cent and, as burned by the Minnesota School of Mines Experiment Station, they have the following characters:

White clay

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
010	Buff	......	......
06	Buff	1	14
01	Buff	4	8
2	Buff	5	6
3	Buff	......	5
5	Buff	......	......

At all of these temperatures the clay is hard and undeformed. The absorption changes indicate the progress of vitrification, but the clay will evidently stand a higher temperature, about cone 10 (2400° F.) without becoming viscous.

Gray clay

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
010	Salmon	......	......
06	Salmon	......	13.0
03	Salmon	3	8.5
2	Salmon	4	6.0
3	Salmon	......	......

This clay is likewise hard, but not viscous at the temperatures reported, but there is evidently enough organic matter in the gray clay to cause danger of the formation of black cores. In a rapid test the brick swelled and cracked at cone 3. Both of the clays, however, show an excellent range of vitrification (450° F.), and are valuable. The white clay has been tested by the Red Wing Stoneware Company with results that were reported as favorable, but the material has not been used because it is not very readily accessible. The overburden is thin and the clay outcrops in a great many places.

At Springfield, some 20 miles up the Cottonwood River from New Ulm, the A. C. Ochs Brick and Tile Company have developed a large body of Cretaceous clays just east of town along the Northwestern Railroad. The clay is 20 feet thick above water level and is known to extend over 20 acres. It is gray, thin-bedded, and contains both pyrite and limonite in concretionary masses an inch or two in thickness. Over most of the area it is covered with common gray drift. The proportion of sand is somewhat variable. The clay slakes in 2 minutes, is highly plastic, and required 29 per cent of water for molding. Its tensile strength is nearly 200 pounds per square inch, but is much less if the clay is rapidly dried. Its shrinkage on drying is about 7 per cent. As tested by the Bureau of Standards, a sample of especially rich plastic shale has the following characters: Auger lamination is serious and there is much danger of cracking on drying. The clay burns buff at low temperatures and is chocolate when vitrified. The range of vitrification is excellent. A porosity of less than one per cent is maintained for over 100° F., without viscosity. Fire shrinkage is less than 5 per cent. It is probably available for roofing tile, if warping can be avoided in drying. A special die might be successful.

The company has been operating for 20 years and has manufactured mostly hollow brick and tile, with a plant consisting of 8 kilns which when full would contain about 4 million bricks. Both soft-mud and stiff-mud brick are manufactured and the strength of the product is excellent. The Minneapolis Building Inspector has the following record: Three well-burned building tile of 91-inch cross section, two holes horizontal, gave an average strength of 965 pounds per square inch. The degree of vitrification easily obtained would indicate that the material is suitable for paving brick, but the wearing qualities have not been tested and few of the bricks are made solid, as the central core makes them lighter for shipment and assists in drying without checking.

An area of similar Cretaceous clays outcrops west of Springfield. Its properties are probably very similar to those of the clay east of town. Mr. Ochs reports, however, that the other clay described is capable of making excellent sewer pipe, whereas that east of town is usually burned to a well-vitrified building block.

Although these different outcrops of Cretaceous clays vary in their properties, some of them are very promising, and there is much evidence that they are present throughout most of the southern part of the county, and are in some places 200 feet in thickness. Analyses are reported in Table II, page 45.

A mile and a half southeast from the center of New Ulm, river clay is known to a depth of 8 or 9 feet over several acres. The upper part of the deposit is dark brown, but the lower part is yellow and more plastic. There is no overburden except the sod, and the usual impurities are scattered patches of sand or even an occasional bowlder and some organic matter. The deposit has been used since 1875 for red brick made with a soft-mud machine which has a capacity of two or three million brick per season.

CARLTON COUNTY

Types of clay,	4. Recent	Alluvium
	3. Pleistocene	c) Gray lake clays
		b) Red lake clays
		a) Red drift
	2. Algonkian (?)	Red clastic series
	1. Huronian	Slates

At Wrenshall, gray lake clays are extensively developed. The town of Carlton as a railroad center has the best location if material were available, and it is hoped that the Huronian slates so prominent here may be made the foundation of some extensive industries with Duluth and Superior as the closest markets. But with the fancy product which doubtless could be made, it should be possible to ship to the Twin Cities and throughout the Northwest.

The Huronian slates outcrop in especially favorable situation along the St. Louis River from Cloquet to Carlton, in glaciated knobs projecting above the general level of the drift. These are not now used, and the past attempts were not particularly successful. They are extensively metamorphosed and have developed a good secondary cleavage though they are not very satisfactory as roofing material. (See Plate II, B.) The variation from a graywacke to a slate is not regular and the folding and crumpling of the formation makes it difficult to predict exactly where good slates are available, but a hasty trip over the district makes it certain that there are many convenient places where the thickness is very great and there is no overburden. The hardness of the material would increase the difficulty of quarrying, but all other conditions seem to be favorable. The slate is of course non-plastic, has very little tensile strength and air shrinkage. It needs only 9 per cent of water for molding. At cone 5 (2250° F.) it is thoroughly vitrified and dark red in color. In 1892 a company was organized under the name of the St. Louis River Slate Brick Company. The superintendent of the company had a patent or secret process which he tested with considerable thoroughness, but nothing has been done for the last eighteen years. The brick produced were red pressed brick of excellent quality, and some are now standing in several Duluth buildings. One disadvantage of the brick was their high specific gravity which increased the freight rate per thousand brick.

A fancy brick could readily be made from this slate by the addition of some more easily fusible drift clays in the neighborhood. Laboratory tests indicate that the clay at Wrenshall which occurs in such quantity a few miles east, and the red bowldery clay so prominent in all the neighborhood around the west end of Lake Superior would be excellent for bonding clays. With 5 per cent of red clay, the mixture became so hard at cone 06 (1900° F.) that it could not be scratched with a knife, and was still undeformed at cone 5 (2250° F.). The color ranged from light to dark red between these temperatures, and the appearance changed from that of common red brick to that of a thoroughly vitrified paving brick. An experiment was made by mixing these clays without crushing the slate to the usual degree of fineness. With lumps up to ¼ inch in diameter, the popular rough appearance of a klinker brick was closely imitated. Fancy brick of this type would be in great demand in the cities at the head of the lake. By using the proper proportion of the fusible red clay, it is possible to get the rough lumpy brick to have the appearance of being glazed, and the excellent characters of the resulting product seem to promise well for this deposit.

Red clastic series. On the railroad above Fond du Lac is an outcrop of shale associated with the red sandstone of the western end of Lake Superior. It is a soft, fine-grained red shale with a few small gray circular areas, which aside from the color do not appear particularly different from the rest of the rock. A chemical analysis of this rock is as follows:[1]

Silica	48.92
Alumina	18.45
Ferric oxide	16.88
Ferrous oxide	0.57
Lime	0.70
Magnesia	3.68
Soda	0.48
Potash	1.32
Water	7.14
	98.14

Red drift, of the common pebbly character, was made use of some years ago for red brick, just north of the town of Barnum. The entire region around Barnum seems to consist of pebbly clay, and the pebbles must be crushed before the clay will make satisfactory products. The clay slakes in 5 minutes, and has a fairly high plasticity, requiring 21 per cent of water for molding. Its air shrinkage is over 6 per cent, and its tensile strength is about 75 pounds per square inch. Burning tests gave the following results:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Red	2	11
02	Red	7	6
5	Red	......	......

The clay becomes hard at cone 04 (1958° F.), and seems to contain enough organic matter so that, if rapidly heated, it develops a black core and swells greatly, but, if thoroughly oxidized, it will stand a temperature of about cone 2 (2138° F.). This is apparently a type of clay that is very widespread throughout the eastern part of the State.

Deposits around the west end of Lake Superior show that during the retreat of the ice the great basin was dammed across so that water was raised to a level of over 300 feet above the present lake. In this lake, known as Lake Nemadji, the melting ice dropped red debris and glacial rivers brought down and deposited various sedi-

[1]Minnesota Geol. and Nat. Hist. Survey, Vol. 5, p. 555.

ments. Water sorting resulted in the formation of some rich laminated clays, but floating ice contaminated some of the clays with bowlders. Streams from the gray drift areas in the west produced gray clays. The ice itself brought red bowldery clays.

The red bowldery clays have thus far been little used in Minnesota, but are worthy of more attention wherever sand or slate is available for mixing. The deposit in this county is known to be at least 60 feet in thickness, and extends across the county for many miles. The southernmost of the accessible outcrops is 4 miles east of Moose Lake, on the Soo Line. Especially favorable occurrences are at Holyoke, and it might be possible to develop a deposit within two miles of Wrenshall where the gray laminated clays are so well developed. The deposit is no doubt continuous between all these localities. It is characteristic of the clay not to show any pronounced lamination, or sandy layers such as are characteristic of most red glacial lake and river clays. The chief distinction between this and common pebbly red drift from the northeast, is the relative abundance of clay and some faint traces of stratification. There is also the fact that it is found on all sides of the west end of Lake Superior, where such a deposit would be expected if it had this origin. It has been spoken of as a "water-laid moraine." The clay slakes in 2 minutes, shows a very high plasticity, and requires 27 per cent of water for molding. Its tensile strength is nearly 100 pounds per square inch, but it cracks rather seriously if rapidly dried. The air shrinkage is 9 per cent. Burning tests indicate a range of vitrification of about 250° F. and the temperature of viscosity is 2100° F.

On account of the rather high shrinkage, a sample of the sand which occurs in the neighborhood and frequently overlies this clay directly, was mixed with the clay to ascertain whether a slight addition might improve the shrinkage and the range of vitrification. This proved to be the case and it is recommended that for hard burned common brick, plants should be located where a supply of sand is available. This is the clay, also, which was used in experimenting with the slates near Carlton for the manufacture of fancy rough brick. As it shows a lower cone of fusion than the slates, it serves very nicely as a sort of glaze and bond between the coarse grains of slate. Its plasticity also is a desirable quality when it is mixed with the non-plastic slates.

The gray laminated clays were washed into Lake Nemadji from the west and are most prominently developed in the vicinity of Wrenshall. They are not much contaminated with bowlders. (See Plate IV.) Five large successful plants are in operation, each with essentially the same type of clay, which here has been developed to a depth of about 50 feet and explored to the depth of 80 feet. Near its upper surface for a few feet, it is more or less broken up and mingled with pebbles, but this condition disappears gradually with depth and the stratification becomes regular. The same gentle undulation visible in the laminated clay north of Minneapolis (described as in Anoka County) occurs here also. The clay when blue or gray makes a cream-colored brick, but the top part of the deposit has not only been disturbed physically, but apparently has been altered chemically by leaching so that its color is red and it burns to red brick. In the upper 10 or 15 feet the disseminated lime has apparently been segregated and is seen in the form of limey concretions which, however, are seldom so abundant as to be serious. The clay extends generally under the flat region, and is seen along the sides of many deeply cut ravines draining into the St. Louis River. It is about 300 feet above the flat on which Superior and West Duluth are located. The detailed structure of the clay is so similar to that of clays found along the Minnesota and Mississippi rivers that its development in interglacial times or soon after the retreat of the ice may be pretty confidently assumed. The lamination is evidently due to the same causes, but the occurrence of this deposit in a place where no river of the same general type is known and the wide extent of the deposit itself, are indications that it formed as a lake deposit rather than as a river silt. The clay slakes in 3 minutes, and shows a fairly high plasticity, requiring 23 per cent of water for molding. The air shrinkage is 4 per cent and the tensile strength is 175 pounds per square inch even when the clay is rapidly dried. Its qualities as shown by tests of the United States Bureau of Standards are as follows: The clay burns buff at low temperatures, but becomes greenish yellow when well vitrified. It has a short range of vitrification when the porosity drops from 42 per cent to nearly none in about 100°. This type of clay is not satisfactory for vitrified ware.

The various plants have a capacity ranging from 40,000 to 140,000 brick per day. Most of the brick are made with stiff-mud machines, although some find the soft-mud process more favorable. Very little hollow ware is produced. Red brick are turned out only when the upper layers of clay are carefully separated from the lower. If uniformly mixed, the 10 feet of red burning clay is not sufficient to affect the color of the 30 feet of cream burning clay. The average quality of the brick made at Wrenshall, as tested by the Experimental Engineering Department of the University, is as follows:

	Crushing Strength in Pounds Per Square In.		Modulus of Rupture	Per Cent Absorption
	Wet	Dry		
Soft-mud cream brick	2809	2166	982	29.4
Stiff-mud cream brick	2894	4762	926	21.7
Stiff-mud sewer brick	4474	5888	1409	18.5
Soft-mud red brick	3354	3233	679	14.9
Stiff-mud red brick	3770	5247	1189	13.3

River alluvium is deposited here and there along the St. Louis River. At Cloquet the river passes through a rather extensive flood plain or flat on which saw mills are located. Before the lumber yards became so extensive as to occupy most of the flat, a small brick yard produced some red, soft-mud brick, which were of fair quality, if one can judge from the buildings still standing at Cloquet. On the northeast side of the river a considerable portion of the flat is still unoccupied and was sampled to determine the quality of the silt of St. Louis River. It slakes at once and its plasticity is low. It requires 21 per cent of water for molding and its air shrinkage is 3½ per cent. Its tensile strength is over 100 pounds per square inch, even when it is rapidly dried. Burning tests gave the following results:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
04	Light red	1	19
02	Light red	2	18
1	Red	5	11
3	Red	7	7

The clay becomes hard at cone 02 (2030° F.), and reaches viscosity a little above cone 4 (2210° F.). It should be capable of burning to an excellent hard red brick, and the refuse from the saw mills should make the fuel problem an easy one.

CARVER COUNTY

Types of clay, 2. Recent ....Alluvium
1. Pleistocene ....b) Gray lake and river clays
a) Gray drift

The only place in Carver County where brick are being manufactured is at Chaska, on the Minnesota River. Gray laminated river clays of the glacial River Warren supply materials for the industry. The section at the clay pit consists of 20 to 40 feet of sand and gravel, stratified in the lower part, below which is dark gray clay to a depth of 100 to 200 feet. It is known to extend under the river valley for hundreds of acres. Its laminated character and geologic relations show that this clay is a deposit from the river, formed at a time when it was greatly swollen by the melting of glacial ice. When the stream was rapid, sandy deposits were mixed into the bank and now are found as irregular pockets and "wells" and streaks, but so scattered that by mixing the product from different parts of the bank a uniform quality of brick may be produced. The clay slakes in one minute, and shows a fairly high plasticity, requiring 28 per cent of water for molding. Its tensile strength is rather low, only one briquette showing over 100 pounds per square inch; and a test for the adhesion of two pieces of clay when pressed together shows very little strength. The average clay shows a shrinkage of 7½ per cent on drying, but when some of the particularly sandy layers were mixed in, this could be reduced to 4½ per cent apparently without injuring the product. The clay burns buff up to a temperature of viscosity, and can be burned hard with very little shrinkage. The absorption is over 20 per cent even in well-burned brick. Clay becomes hard at cone 02 (2030° F.), and viscous at cone 4 (2210° F.). The character is very similar when half the mixture is composed of the particularly sandy layers. Four plants using this clay are in successful operation. All are under one management and use essentially the same method. The capacity of the four plants varies from 45,000 to 140,000 brick per day. Last year 50 million brick were made at Chaska. Coal is the only fuel available, and a large proportion of the product are solid cream-colored brick, some of which are made in the soft-mud machine. Three of the plants have facilities for making hollow ware, and three of them are provided with steam shovels for winning the clay. Some of the products from Chaska have been tested by the Minneapolis Building Inspector. The results are as follows: Two sewer brick showed a crushing strength of 4,250 pounds per square inch. Four miscellaneous brick in one set gave an average strength of 1,600 pounds per square inch. A set of 14 brick, probably selected with some care (though this was not stated), had an average crushing strength of 2,635 pounds per square inch. Two hollow brick had a strength of 236 pounds per square inch. One hollow tile with three openings horizontally had a strength of 158 pounds per square inch.

The Experimental Engineering Department of the University of Minnesota obtained the following results on Chaska brick: Five soft-mud well-burned brick tested dry had an average crushing strength of 2,081 pounds per square inch. The modulus of rupture was 658 pounds per square inch and the absorption 22.2 per cent. The hollow building blocks have an average strength of 505 pounds per square inch. The modulus of rupture was 600, and the absorption 10.0 per cent. Wet brick had about the same strength as the dry ones.

The other clays of the county are of the gray drift and alluvium and are inferior, so far as known, to the deposits at Chaska.

CASS COUNTY

Types of clay, 2. Recent ....Lake clays
1. Pleistocene ....b) Gray drift
a) Red drift

Cass County is covered with gray drift except in its two southeastern corners, where the red drift is exposed. Possibly lake clays of value may be discovered near White City.

CHIPPEWA COUNTY

Types of clay, 3. Recent ....Alluvium
2. Pleistocene ....Gray drift and gray laminated clay
1. Archean ....Residuals

Throughout the county, the gray drift, rarely free from pebbles, is abundant. At Montevideo it was abandoned for river clays and now the latter are abandoned also. Considerable clay is visible in the flat near the mouth of Chippewa River. Opposite Minnesota Falls are some small outcrops of clay residual from granite. These are not likely to be of much importance. N. H. Winchell reports[1] the same from Tunsberg. O. E. Meinzer reports well records[2] showing 70 feet of white clays, Cretaceous and Archean, at Montevideo, at a depth of several hundred feet.

The gray drift opposite Granite Falls was freshly exposed by a railroad cut, deep enough to reach unweathered gray drift below the yellow drift. (See Fig. 2.) Both the yellow and the gray drift are well supplied with limestone and other pebbles and contain about the proportion of sand found in the Hutchinson material. The clays slake in 2 minutes and are highly plastic, requiring 17 per cent of water for molding. The tensile strength is about 150 pounds per square inch and the shrinkage on drying less than 4 per cent. These samples require a temperature for vitrification slightly above the average.

About 5 miles northeast of Appleton, and a mile east of the Great Northern Railroad, the digging of a well has revealed a plastic blue clay which is apparently of the laminated type. The clay slakes at

[1]Winchell, N. H., Final Rep. Minnesota Geol. & Nat. Hist. Survey, Vol. 2, p. 213.
[2]Meinzer, O. E., Water resources of Southern Minnesota: U. S. Geol. Survey. Water-Supply Paper, No. 256, p. 153.

once and shows a high plasticity, requiring 34 per cent of water for molding. Its air shrinkage is 4 per cent and its tensile strength is over 150 pounds per square inch, though rapid drying is injurious. Burning tests proved it to be of very poor quality. The brick burns salmon color and shows very little shrinkage up to the temperature of cone 02 (2030° F.), where it has an absorption of 28 per cent. At cone 01 (40° higher) the shrinkage increased to 16 per cent, the absorption decreased to 2 per cent, and the clay is viscous. It is certainly not safe to burn the clay hard.

CHISAGO COUNTY

Types of clay, 2. Pleistocene.............c) Red lake and river clays
b) Gray drift
a) Red drift
1. Cambrian..............Dresbach shale

At Rush City a plant operating for several years made red brick from till. Later a particularly good clay was developed 1½ miles south of town. This is apparently to be classified as the outwash from the front of the ice sheet. It may have formed from the ice sheet which brought in the gray drift, but the gray drift throughout this county is rather thin, and enough material from the northeast has been incorporated into this outwash so that it burned red, and is here classed as part of the red drift. The clay slakes at once, and is highly plastic, requiring 27 per cent of water for molding. The tensile strength is between 50 and 75 pounds per square inch, and the air shrinkage between 5 and 6 per cent. Burning tests resulted as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
06	Salmon	0	20
05	Salmon	0	18
01	Red	5	10
3	Red	7	6
4	Red	......	......

The clay becomes too hard to be scratched with a knife at cone 05 (1922° F.), and is apparently not close to viscosity at cone 4 (2210° F.). It has thus a range of vitrification of about 300 degrees or more, and is capable of being burned to a very hard and excellent product. Brick have been made here for several years and a spur track was laid from the Northern Pacific Railroad half a mile away. It is claimed that the work was abandoned on account of the difficulty of getting expert men to carry on the work, but if the qualities of the clay are as excellent as they appear to be, and there is any favorable market, it seems unfortunate that this plant has been abandoned.

Hills of gray drift cover a large part of the county and constitute the most eastern extension of this type of material. A sample was taken at Center City where the exposure is 40 feet thick. The clay slakes in 2 minutes, and is highly plastic, requiring 19 per cent of water for molding. Its air shrinkage is less than 4 per cent and its tensile strength is over 150 pounds per square inch. As compared with the material profitably used at Hutchinson, the clay at Center City is a trifle more sandy, containing 33 per cent instead of 30 per cent of sand. The difference should not be one of any importance, as the range of vitrification of the clay is essentially the same.

At North Branch a small brick yard was started many years ago in Secs. 14 and 15, just west of the town, making use of some patches of red drift which come to the surface here and there through the gray drift which covers it in most places. At Sunrise the material is evidently similar and was used in 1856. Red laminated clay also is exposed near Sunrise. At Taylors Falls, red laminated clay occurs on the Wisconsin side, but on the Minnesota side it is covered by gray drift.

The Dresbach contains a thin shale layer in the bluffs near the Dalles at Taylors Falls, and, though of fair quality, it is probably too thin to use. There is not more than 10 feet of siliceous shale about 30 feet below the railway track. It softens in water but does not slake. After grinding, it may be molded with 20 per cent of water and develops a tensile strength of over 50 pounds per square inch. Its air shrinkage is 3.5 per cent. Burning tests resulted as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Salmon	0.0	17
03	Salmon	0.0	16
01	Salmon	0.3	15
1	Red	0.5	6
3	Red	0.6	2

It becomes too hard to scratch with a knife at cone 03 (1994° F.), and viscosity is reached at cone 3 (2174° F.). The range, therefore, is 180°+. If abundant, this material might be used for hard burned products.

CLAY COUNTY

1. Cretaceous ....b) Silts of Red River Valley

Types of clay, 2. Pleistocene...........a) Gray drift

Shale

Dark blue Cretaceous shales were found at Fargo across the river from Clay County, at a depth of 220 feet, and are known to be over 40 feet thick. No doubt they extend into Clay County.

At Moorhead several plants have been installed to make use of the thin upper leached and oxidized portion of the silts of the Red River Valley. Only 16 inches of clay here is of good quality. If the underlying clay is mixed with this, much trouble is encountered in drying. It is necessary to work such a large area to obtain the clay when it is so thin, that at most plants a few inches of soil have been stripped off from the clay to be used and spread upon the surface of the shallow pit from which the clay has already been removed. This allowed the continuous use of the soil for farming purposes, except over the few acres which were being actively worked. The clay slakes in 1 minute, and its plasticity is low. It requires 22 per cent of water for molding. Its tensile strength is well above 100 pounds per square inch, even when it is rapidly dried, and the air shrinkage is 5 per cent. Burning tests gave the following results:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
04	Buff	0	33
01	Buff	0	33
2	Buff	1	29
5	Buff	......	......

The clay becomes hard at cone 3, although satisfactory brick can be made at somewhat lower temperatures. Its temperature of fusion is rather higher than that of most of the clays which contain so much lime. It has a range of vitrification of nearly 200°. The several plants which have been operating in this neighborhood produced soft-mud brick and the capacity of each was rather limited. They are no longer operating.

At Barnesville, samples were taken from two points, one a mile east of town, and one about the same distance north at the site of an old brick yard. Both of these samples were taken so as to include several feet of the blue clay as well as the very thin layer of leached material on top. Scattered crystals of gypsum appear in one of the samples. The clays slake in 2 minutes, and are highly plastic, requiring 39 per cent of water for molding. When very carefully dried, the briquettes have a strength of over 100 pounds per square inch, but they crack to pieces unless dried with care. Furthermore, a test of the adhesive quality of pieces of wet clay pressed together shows that the use of an auger machine might result in very defective structure. The shrinkage on drying is 7 per cent. Both the clays burn buff at temperatures as high as 2000°

F. The sample taken from the east side of town shows a good range of vitrification and reaches viscosity at cone 4 (2210° F.). It should be capable of making even better and harder brick than formerly were made north of town.

CLEARWATER COUNTY

Pleistocene gray drift is the only clay reported in the county, and it needs cleansing before it is capable of successful use. Lakes are notably less abundant than in neighboring counties.

COOK COUNTY

Red clays are reported in considerable abundance and are apparently like the "water-laid moraine" so common around the shores of Lake Superior. The following analysis of a sample sent to the University of Minnesota in 1897, by Chester McKusick, is reported by Dr. C. P. Berkey.

Analysis of Red Clay from Cook County

Silica	53.39
Alumina	14.259
Iron oxide	13.706
Lime	3.033
Magnesia	1.740
Alkalies	not reported
Combined water	9.995
Carbon dioxide	4.278
	100.451

COTTONWOOD COUNTY

Types of clay,	3. Recent	Lake clay
	2. Pleistocene	Gray drift
	1. Cretaceous shale	

About half a mile from the station at Windom is a deposit of gray drift, which has been explored to a depth of 8 feet over a great many acres. In parts of the neighborhood it is undoubtedly of a greater thickness. The clay slakes in 3 minutes and is fairly plastic, requiring 24 per cent of water for molding. Its tensile strength is about 50 pounds per square inch, and the air shrinkage is 6 per cent. Burning tests by the Minnesota School of Mines Experiment Station are as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
03	Salmon	1	20
01	Salmon	7	17
1	Brown	8	5
5	Brown	......	......

The clay burns hard at cone 03 (1994° F.), and is viscous at about cone 3 (2174° F.). An attempt was made to use this clay at the Windom Brick and Tile Factory, and the product is said to have been satisfactory.

A lake clay which has been used by the Bingham Lake Brick and Tile Company since 1904, occurs on the northeast side of Bingham Lake. It is known to be 9 feet thick over several acres. A few small limestone pebbles seem to have been washed into the upper layers of the clay, but the main part of the deposit is free from them. The clay slakes in 1 minute, and is highly plastic, requiring 32 per cent of water for molding. The tensile strength is over 125 pounds per square inch, but this is decreased somewhat by rapid drying. The air shrinkage is 7 per cent. Burning tests made by the Minnesota School of Mines Experiment Station are as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
04	Salmon	1	22
03	Red	2	20
02	Red	3	19
01	Brown	9	6
2	Brown	......	......

The clay becomes too hard to be scratched with a knife at about cone 03 (1994° F.), and reaches viscosity at cone 2 (2138° F.). The company have specialized in the manufacture of tile rather than brick, of which they can produce about 650,000 per year.

Cretaceous shales at depths of about 300 feet are found by drilling.

CROW WING COUNTY

Types of clay, Pleistocene..............b) Gray lake and river clay
a) Red drift

About a mile northeast of the town of Brainerd, a yard was started along the banks of the Mississippi River in 1876 to produce cream brick from laminated clays. The clay is exposed in the bluff and overlaid by about 20 feet of sand. Where the sand has protected it from weathering, it is uniformly gray in color, but work at this point has been abandoned, as most of the easily accessible clay has been used up and the removal of 20 feet of sand to obtain about 30 feet of clay did not appear to be profitable. The clay is of excellent quality, and either this or some neighboring deposit may yet be used, though between this locality and the town of Brainerd, no such clay seems to be available.

The clay slakes at once, and shows a fairly high plasticity, requiring 24 per cent of water for molding. Its air shrinkage is 4 per cent and its tensile strength well above 100 pounds per square inch even when rapidly dried. Burning tests by the Minnesota School of Mines Experiment Station are as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
02	Buff	1	25
1	Buff	2	22
2	Buff	2	22
4	Buff	7	11

At cone 01 (2066° F.) the clay becomes too hard to be scratched with a knife, and it reaches viscosity at cone 4 (2210° F.).

In 1886, at about the time this clay along the river was abandoned, it was found that there was an outcrop of similar material a few hundred yards east where a tributary stream had eroded the overlying sand. A brick yard is now in operation upon this deposit and, though the upper portion has been leached to a yellow color, it is essentially similar in origin. It seems rather more sandy, however, and it burns to a red brick. It probably is available under about 200 acres of land. The clay slakes in 4 minutes, is highly plastic, and requires 24 per cent of water for molding. Its tensile strength is only about 50 pounds per square inch, and its air shrinkage is 8 per cent. Burning tests are as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Salmon	1	16
03	Salmon	3	12
1	Red	6	3

The clay becomes hard at cone 05 (1922° F.), and viscous at cone 1 (2100° F.). The plant has machinery with a capacity of 20,000 brick per day, but works only half day shifts, producing sand-mold common brick.

DAKOTA COUNTY

Types of clay, 3. Recent.................Alluvium
2. Pleistocene.............b) Loess
a) Red and gray drift
1. Decorah shale

The Pleistocene and Recent clays are not important. A small brick yard at West St. Paul makes use of red burning leached drift. The clay may be made up of a sort of outwash. It slakes at once, and its plasticity is rather low, though it requires 28 per cent of water for molding. Its tensile strength is over 100 pounds per square inch, and the air shrinkage is less than 4 per cent. Burning tests are as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
04	Salmon	1	18
01	Red	2	16
1	Red	5	10
3	Red	7	8
5	Red	......	......

The clay becomes hard at cone 01 (2066° F.), and is nearly viscous at cone 5 (2246° F.). It should, therefore, be possible to burn it to a very excellent hard product. The plant which has been working this deposit is relatively small, and is now practically abandoned.

The most important formation is the Decorah shale, which is best developed along the Mississippi River bluffs at West St. Paul. The distribution of the Decorah shale in this county may be seen by reference to the State map. (See Plate I.)

In West St. Paul and Mendota the geologic section is as follows:

		Thickness
7.	Drift	65 feet
6.	Shale and limestone (many layers of limestone)	40 feet
5.	Hard limestone	3 feet
4.	Shale (½-inch lenses of limestone)	40 feet
3.	Limestone	18 inches
2.	Shale	3 feet
1.	Platteville limestone	12 feet

This is about the maximum thickness in the State. The lower part of of the large body of shale, number 4 of the section, seems to differ slightly in character from the higher shale beds which alternate with the limestone. Results of tests of samples of each horizon are as follows:

1. The lower shale is smooth and green in color, slakes in 2 minutes, and is very highly plastic. It requires 28 per cent of water for molding, has a tensile strength of nearly 100 pounds per square inch, and is unaffected by rapid drying. Its tensile strength is remarkable in that two pieces which have been cut apart and again pressed together, as by the auger machine, readily adhere with about as much strength as before. This eliminates most of the common defects of bricks made in Minnesota.

The air shrinkage of this clay is less than 6 per cent. If rapidly burned, there is a strong tendency to the formation of black cores with the consequent swelling and destruction of the brick, but if the organic matter is carefully oxidized in the early part of the process, the results are as follows:

Cone No.	Color	Shrinkage Per Cent	Per Cent Absorption
010	Salmon	4	12
06	Salmon	6	9
04	Red	......	......
02	Brown	......	......

The clay burned too hard to be scratched with a knife at cone 010 (1742° F.) and was not viscous at cone 02 (2030° F.), if burned very slowly to avoid black cores. In the laboratory tests an efflorescence appeared on the brick taken from the furnace which might indicate a tendency to the production of "kiln white."

2. The upper shale can usually be quite cleanly separated from the interbedded limestones and gives about the same results as the lower bed, except in the matter of color which is much lighter. A little less water is required to make it plastic. The clays yield the following analyses:

Table VI. Analyses of Decorah Shale at West St. Paul

	1	2
Silica	50.81	54.66
Alumina	20.25	24.04
Iron oxides	5.18	6.53
Titania	0.50	0.66
Lime	4.05	0.45
Magnesia	2.13	1.08
Soda	0.28	0.47
Potash	5.69	5.37
Moisture	2.16	2.35
Ignition	8.92	5.15
	99.97	100.76

1. Upper layers }
2. Lower layers } F. F. Grout, Analyst.

The plant of the Twin City Brick Company, one of the largest in the State, is located at the boundary line between West St. Paul and Mendota. Here this company has a very extensive quarry and produces brick and hollow ware, with a capacity of nearly 100,000 a day. Brick are burned to about 2100° F., varying considerably with the type of product desired. The main variations in the products are controlled (1) by the proportion of upper and lower shale used; (2) by the temperature used in burning; and (3) by the supply of fuel and air at the various stages of burning, resulting in oxidation and reduction. Work was begun in this neighborhood over 20 years ago and has progressed with many changes in method and control, and the final consolidation and success have been largely due to the present management. Market conditions are of course excellent. Various details of manipulation have been patented and the ingenious devices which have been developed on the ground are worthy of careful study by any one planning to make use of Decorah shale. Although the shale burns red under normal and laboratory conditions, it is capable of being altered by the control of the fuel supply and by shutting off the supply of air so that the resulting brick are given various dark shades of color. Fancy brick, front brick, and klinker brick are produced in such quantities and bring such high prices that the production of common brick and drain tile has practically ceased at this plant. One of the many interesting special products is an interlocking tile for building block.

The following test of the products made in West St. Paul are available. Professor Talbot, of the University of Illinois, reports a crushing strength of 1,100 pounds per square inch, for hollow block about 4 x 4 x 13 inches, with the opening through the block in a horizontal position. Also a strength of 3,500 pounds per square inch for hollow block about 4 x 4 x 4 inches, with the opening through the block in a vertical direction. The City Building Inspector of Minneapolis, in testing the hollow block, found a crushing strength of 900 pounds per square inch as an average of ten tests on blocks 4½ inches square and 12½ inches long. The Building Inspector also tested some solid brick, finding an average of 3,300 pounds per square inch, with a minimum of 1,775 and a maximum of 6,250, in ten bricks tested.

DODGE COUNTY

Types of clay, 2. Pleistocene ....b) Gray lake clay
a) Gray drift
1. Decorah shale

In the eastern portion of the county, along the head waters of the various branches of the Zumbro River, the Decorah shale and the Galena limestone outcrop. The Decorah shale probably underlies most of the county and affords the most promising formation for the manufacture of clay products. Shales, without a very heavy overburden, outcrop in the vicinity of Mantorville and Kasson within a mile or two of the railroad. These should be investigated as a probable source of brick material. Gray drift, such as is being worked at West Concord for the manufacture of drain tile, covers most of the county. It contains numerous pebbles and is underlaid by sand.

At West Concord the pit exposes 8 feet of gray drift which extends over many acres. The pebbles are not quite as numerous as in the average gray drift, but were responsible for the failure of an attempt to make use of the clay. After fine grinding, the clay behaves as follows: It shows low plasticity, and requires 22 per cent of water for molding. Its air shrinkage is 5 per cent. Burning tests by the Minnesota School of Mines Experiment Station gave the following results:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Salmon	1	15
01	Red	3	14
1	Red	5	8
3	Red	6	7
5	Brown	......	......

The clay becomes too hard to be scratched with a knife at cone 02 (2030° F.), and is still undeformed at cone 6 (2282° F.). It would seem that fine grinding and burning to a fairly high temperature would make it possible to use this clay with satisfactory results.

Gray laminated clays occur about 2 miles southwest of Hayfield on the Great Western Railway, in a deposit which is known to cover many acres to a depth of 30 feet. This has been exposed along the banks of the creek and most of it is blue and sandy, though weathered yellow near the top. There is practically no overburden along the creek, but it increases to 15 feet of soil and drift at a short distance away. A few small pebbles were observed, but they do not seem to be a serious disadvantage. The clay slakes in 4 minutes, shows fairly high plasticity, and requires 19 per cent of water for molding. Its shrinkage on drying is 4 per cent and its tensile strength is about 150 pounds per square inch even when it is rapidly dried. Burning tests resulted as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Salmon	1	16
01	Salmon	2	13
2	Brown	6	5
4	Brown	......	......

The clay becomes hard at about cone 02 (2030° F.) and reaches viscosity at cone 4 (2210° F.) If market conditions are found favorable, this clay should supply material for a brick industry.

DOUGLAS COUNTY

Types of clay, 1. Recent..............................Lake clay
2. Pleistocene..........................Gray drift

At many points attempts have been made to work the gray drift to make common brick and, where the limestone pebbles are less abundant than usual, some success has attended the effort. At Alexandria gray drift is very favorably situated with respect to market and shipping facilities. A sample of the drift taken at the intersection of the Great Northern and the Soo lines was very much like the material used at Hutchinson, but a trifle more sandy. This should not be a serious defect, since it is possible to discard some of the sand in the pit, and the clay vitrifies with the same range as that from Hutchinson. North of Alexandria, at the station of Miltona, a brick yard is in operation on a small scale, using a few feet of the leached upper part of a mass of gray drift from which the limestone pebbles are almost entirely gone. This leaching has apparently been effective over an area of several acres and there should be enough clay to keep a small plant in operation for several years. The air shrinkage of the clay alone is 11 per cent, but a larger proportion of sand is added in practice and the shrinkage thereby reduced, although most of the available sand contains a good deal of lime, and an excess is decidedly injurious.

At the northeast edge of the town of Alexandria, the McKay Brick Company for several years made brick from a bog deposit extending over 10 acres and known to extend to a depth of more than 5 feet, but the bog was so wet that only 5 feet have been used. Very few pebbles have been washed into this deposit. The clay is so rich that 10 or 15 per cent of sand is usually added. This is found at several convenient points throughout the neighborhood. The clay slakes in 2 minutes and is highly plastic, requiring 22 per cent of water for molding. The tensile strength is 175 pounds per square inch and is well above 100, even if the clay is dried without special precautions. The air shrinkage is 4 per cent. Burning tests gave the following results:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Salmon	2	15
02	Salmon	3	12
1	Red	5	8
3	Red	6	6
5	Brown	......	......

The clay burns too hard to be scratched with a knife at cone 03 (1994° F.), and does not reach viscosity at cone 5 (2246° F.). It should burn to a very excellent hard vitrified product, though apparently it has been used only for a good grade of common brick. It is unfortunate that a disagreement among the owners caused the abandonment of the plant.

In the northwest corner of the county, laminated clays occur along the shores of Pelican Lake, and on the islands in the lake.

These may be partly of glacial origin, but as the outlet of the lake is now being eroded and the lake level is being lowered, recent deposits are being continuously exposed. Three or four feet of sandy soil overlies the clay, and some ferruginous concretions are visible in the clay itself. It slakes in 3 minutes and is very highly plastic, requiring 31 per cent of water for molding. The tensile strength is 190 pounds per square inch, though considerably less if the clay is rapidly dried. The drying shrinkage is 7 per cent. It burns to a good buff color and vitrifies at about cone 2 (2138° F.) This should be developed if there is any market for clay brick. Similar clay is said to occur on Abbots Point, on the south shore of Lake Miltona, not as well situated as that on Pelican Lake.

FARIBAULT COUNTY

Types of clay, Pleistocene...............b) Gray lake and river clays
a) Gray drift

Gray drift covers almost the entire county, but is too pebbly at most places to be of much economic importance. The fine, plastic, laminated clay has been used at Winnebago and Blue Earth for brick and tile. The only clay plant in operation in the county is located at Winnebago, although Blue Earth City supplies the raw clay which is used at the Fairmont plant where it is shipped.

The deposit at Blue Earth is known to extend to a depth of 20 feet over 10 acres and probably has much greater dimensions both vertically and areally. It is covered with only 2 or 3 feet of soil, and near the top has a layer in which there are many lime pebbles. The clay slakes in 2 minutes and is highly plastic, requiring 33 per cent of water for molding. Its tensile strength is less than 50 pounds per square inch in the average of 4 tests. Its air shrinkage is 8 per cent. Burning tests resulted as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Red	3	23
03	Red	4	18
01	Red	5	16
2	Red	......	1

The clay burns hard at cone 04 (1958° F.), and is viscous at cone 2 (2138° F.) This clay is now being used by the Fairmont Drain Tile and Brick Company, located at Fairmont in Martin County. The capacity of the plant is 25,000 tile per day. The plant was erected at a cost of $150,000 with the expectation of making use of a local clay, at Fairmont, but this was found to be so full of limestone pebbles as to be useless. The whole surrounding country has been prospected for a suitable clay and only two or three deposits were found available. The Blue Earth material is the only Minnesota clay now used, but some small amounts are imported from Mason City, Iowa. Hollow brick and tile are being produced.

At Winnebago, in Faribault County, along the Milwaukee tracks west of town, there is a deposit of about 70 acres of clay which is known to extend to a depth of 30 feet. It is covered with only 2 or 3 feet of soil. Limestone pebbles occur here and there in this deposit, especially near the top, but the Winnebago Drain Tile Company, which has a good plant making use of the clay, have a process of treating the clay with salt to counteract the effects of lime. This is said to work very satisfactorily. The details of the process, or the particular salt used, the company was not free to make public.

FILLMORE COUNTY

Types of clay, 4. Pleistocene ....Loess
3. Cretaceous clay
2. St. Lawrence, Galena, and Maquoketa, not important
1. Decorah shale

The Decorah shale occurs on terraces at an elevation of from 1,070 to 1,130 feet along the banks of the Root River and its several branches. It constitutes a persistent spring horizon. The distribution can be seen on the map, Fig. 12.

Preston, the county seat, has an abundance of these green shales, some of which are favorably situated for development. Chatfield is also well supplied with the shale. The average thickness of the Decorah shale in Fillmore County is only about 20 feet. A sample was taken in Elmira township. In working and burning, this proved to be essentially similar to the shale at West St. Paul, though there were some indications that rapid drying might be harmful. The range of vitrification is over 400° F. (Cone 010 to cone 2.) This shale is not used in the county and is recommended as the most valuable material available.

Although clays thought to be of Cretaceous age are known in Fillmore County, they have not yet been developed. Half a mile north of the village of Hamilton, along the road between Fillmore and Mower counties, is a clay which seems to be Cretaceous, but may possibly have been reworked by glacial action. It is red near the surface, but gray and carbonaceous below. Its thickness is nearly 20 feet, and it is estimated that it extends over 30 acres. The clay slakes at once and is very highly plastic, requiring 45 per cent of water for molding. Its air shrinkage is 11 per cent. It burns to a red color and becomes hard at a low temperature, not over 1750° F. If rapidly heated, the organic matter causes swelling and black cores, but if fully oxidized it can be heated to cone 2 (2138° F.) without deformation. It should, therefore, be capable of producing good vitrified ware.

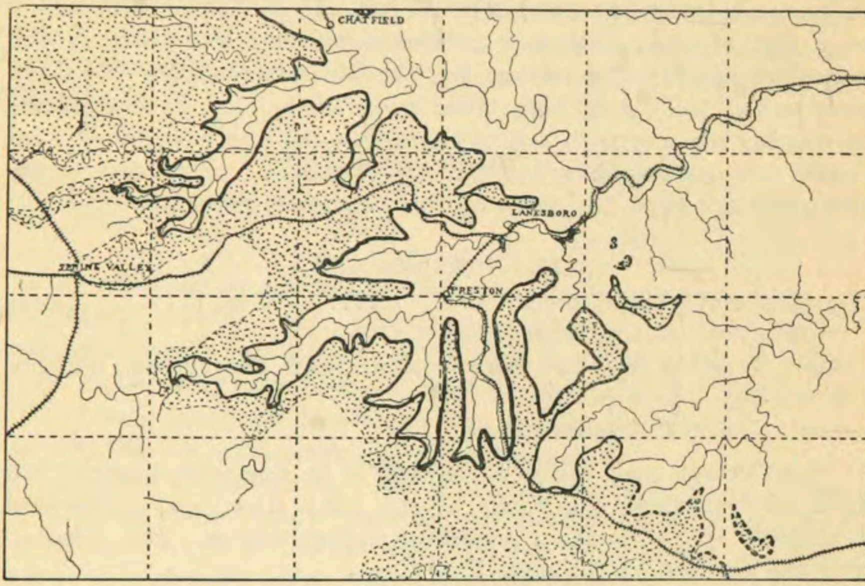


FIGURE 12. MAP OF FILLMORE COUNTY. DOTTED AREA UNDERLAID BY DECORAH SHALE.

The loess covers the eastern two-thirds of the county, where it forms a mantle varying in thickness from 2 to 20 feet over the Paleozoic formations. Its greatest thickness is seen at the base of the slopes along the valley. On the high prairie land, although it is not so thick, it is much more evenly distributed. Many abandoned yards have used it in the past. Such yards occur at Rushford, Peterson, Whalen, Lanesboro, Fountain, Spring Valley, Carimona, Forestville, Harmony, and Mabel. Material for red brick is still available at each of these places.

At Preston is one of the most important of the loess deposits. The section exposed is as follows:

Loess loam	6 inches
Yellow loess	10 feet
Bluish gray loess (to an unknown depth)	5 feet exposed

The yellow loess is the part of the deposit being used and the blue-gray material is reported as being too plastic for use in a sand-mold brick plant. The deposit is very extensive and will furnish material for good common red brick for many years. The plant is located about a mile north of town. The yellow clay slakes in 1 minute and shows a rather low plasticity. It requires 23 per cent of water for molding and its air shrinkage is 2½ per cent. Burning tests resulted as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
04	Salmon	2	18
03	Red	2	18
01	Red	4	15
1	Red	7	8
3	Red	9	2
5	Red	......	......

The clay becomes hard at cone 04 (1958° F.), and reaches viscosity at cone 4 (2210° F.). The U. S. Bureau of Standards reports it unsuited for auger machine molding; also that it is likely to crack in burning.

A sample of the underlying blue clay showed essentially the same properties, and, so far as indicated by laboratory tests, it could probably be worked into brick and burned to a satisfactory product. It was a little more porous as burned to the low temperature, and required a little higher temperature to make it hard. The plant here has a capacity of 30,000 brick per day and is steadily operated.

FREEBORN COUNTY

Types of clay, 2. Recent...........Swamp clay
1. Pleistocene........b) Gray lake and river clays
a) Gray drift

The glacial drift is too pebbly to be of much value.

Two clay plants only are worked in Freeborn County: one at Albert Lea, and one at Glenville, about 12 miles southeast of Albert Lea. An old abandoned plant exists at Conger. The material used at these places consists of laminated clays of a blue-gray or yellow color. Other deposits of this nature might be discovered at several places in this region.

Within a mile north of Glenville, the Acorn Brick and Tile Company have developed a deposit of laminated clay which occupies at least 10 acres and is known to be over 10 feet thick. Where exposed, the color is yellowish brown from oxidation. The overburden is from 2 to 3 feet. The clay slakes at once, shows fairly high plasticity, and requires 30 per cent of water for molding. Its air shrinkage is nearly 8 per cent, and its tensile strength is very low, not over 25 pounds per square inch in the briquettes made. From the appearance of these briquettes, it is evident that flaws may develop upon drying, even when great care is used. The clay burns red and has a fair range of vitrification, reaching viscosity at cone 3 (2174° F.) The plant produces both red brick and drain tile, which are said to be of fair quality, though the plant was not operating at the time it was visited.

Two and a half miles southeast of Conger, in this county, is a deposit of 30 feet of laminated clay extending over nearly 100 acres, with the usual section beginning with 3 feet of black soil, and followed by 8 or 10 feet of yellowish clay, below which is the blue or gray clay. At the base of this section a gravelly bed occurs. In 1904, a company was organized to work this deposit, but shipping facilities were inadequate and the work ceased in about 4 years. Both the gray and the blue clay were used as dug from the pit, with the addition of some sand which had to be hauled from a distance. No tests were made to determine whether the blue and gray clays were similar.

The Albert Lea Brick and Tile Company have erected a plant just outside the city limits north of the town of Albert Lea, where there is a large hill of perhaps 25 acres, in which the formations are arranged as follows: an overburden of 2 or 3 feet of soil, 16 feet of yellow clay, 26 feet of blue clay. The clay is laminated and shows the usual irregularity of clays of this type. The blue clay is more plastic than the yellow, and slakes rather more promptly, but both are excellent in these respects. The blue clay shows a rather lower tensile strength, about 60 pounds per square inch, which is greatly injured on rapid drying, as the manufacturers have discovered at considerable cost. The yellow clay is much more satisfactory, having a tensile strength of over 100 pounds even when rapidly dried. A test for the adhesive properties of two wet pieces of clay after being pressed together and dried shows that it is not very great and there is an indication that the auger laminations would be serious. This also has been the experience of the company, and they have sought to use about 25 per cent of non-plastic material, such as cinders, burnt clay, or sand, to overcome this lamination. The drying shrinkage of the blue clay is 6 per cent and of the yellow, 3 per cent. Burning tests at the Minnesota School of Mines Experiment Station are as follows:

The Blue Clay

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
06	Salmon	2	30
02	Salmon	4	26
2	Yellowish green	......	......

The Yellow Clay

05	Salmon	1	37
03	Buff	1	36
1	Buff	1	36
2	Greenish yellow	......	......

The clay burns to a fairly satisfactory product at these lower temperatures, but does not become very hard until nearly at the temperature of viscosity. The range of vitrification is approximately from cone 1 to cone 2. Tests of a mixture of the blue and yellow clays gave results similar to those obtained when the clays were burned separately.

The U. S. Bureau of Standards report[1] the following: An extremely fine-grained clay from Albert Lea, Minnesota, of considerable plasticity, but troublesome to dry. The specific gravity of the powdered dry clay is 2.58. Linear shrinkage in per cent of the wet length is 9.79. Mechanical analysis by elutriation gave:

Coarser than 120-mesh	0.24
Average .577 mm. diameter	0.21
Average .0354 mm. diameter	1.04
Average .0167 mm. diameter	0.96
Average .005 mm. diameter (and less)	97.31

The viscosity of the clay suspension was determined (water=1) to range from 1.1 when containing 7.5 per cent by weight of clay to 2.21 when containing 43 per cent by weight of clay, but the curve was not very straight. When the clay was heated to a temperature of 200° to 400° C., and cooled and worked up to the plastic state, it required less water than before to bring it to good molding consistency. The change was greatest (43 to 36) between 200° and 250°. After a treatment of this sort the volume shrinkage is much less than before and rapid drying causes no injury. The improvement in this clay at 350° is remarkable. Ninety-five per cent of the bricks were cracked before heating; none after. A proposed test[2] for plasticity using the absorption of a colored dye indicates a much great plasticity than in the others tested in this same study.

[1]Bleininger, A. V., Preheating clays: U. S. Bureau of Standards, Bull., Vol. 7, No. 2.
[2]Ashley, H. E., Colloid matter in clays: U. S. Geol. Survey, Bull. No. 388.

The following analysis was made by Mr. G. W. Walker, of the University of Minnesota, for Mr. M. R. Rusfeldt of the company.

Analysis of Gray Laminated Clay from Albert Lea

Silica	54.90
Alumina	13.94
Iron oxide	5.16
Lime	7.36
Magnesia	3.28
Potash	1.88
Soda	2.13
Titanium	0.84
Loss on ignition	12.54
	102.02

The bricks made of the gray laminated clay of Freeborn County have been tested by the Experimental Engineering Department of the University. The stiff-mud bricks had a crushing strength of 2463 pounds per square inch. The absorption was 25.8 per cent.

A deposit consisting of an extremely fine-grained silty clay, which is possibly in the nature of fullers' earth, occurs in a swamp in Secs. 11, 12, 13, and 14, T. 103 N., R. 20 W. The material could probably be used for common brick or drain tile. The following analyses are available, the first two of which were made by Mr. A. D. Meeds, and the last two by Dr. G. B. Frankforter, both of Minneapolis.

Analyses of Freeborn County Swamp Clay

Silica	55.52	57.60	59.37	57.62
Alumina	13.55	14.19	11.82	14.35
Iron oxides	3.99	2.89	6.27	2.50
Lime	8.00	7.00	6.17	8.11
Magnesia	3.16	3.51	2.09	2.98

The remaining 15 per cent is largely water and carbon dioxide, with traces of phosphoric acid, chlorine, and the alkali metals. Water constitutes nearly 13 per cent.

GOODHUE COUNTY

Types of clay, 4. Recent .... Alluvium
3. Pleistocene .... b) Loess
a) Gray drift
2. Cretaceous clay
1. Decorah shale

Goodhue County is noted for its good clays and its clay-working industries. The most important sources of clay are the Cretaceous.

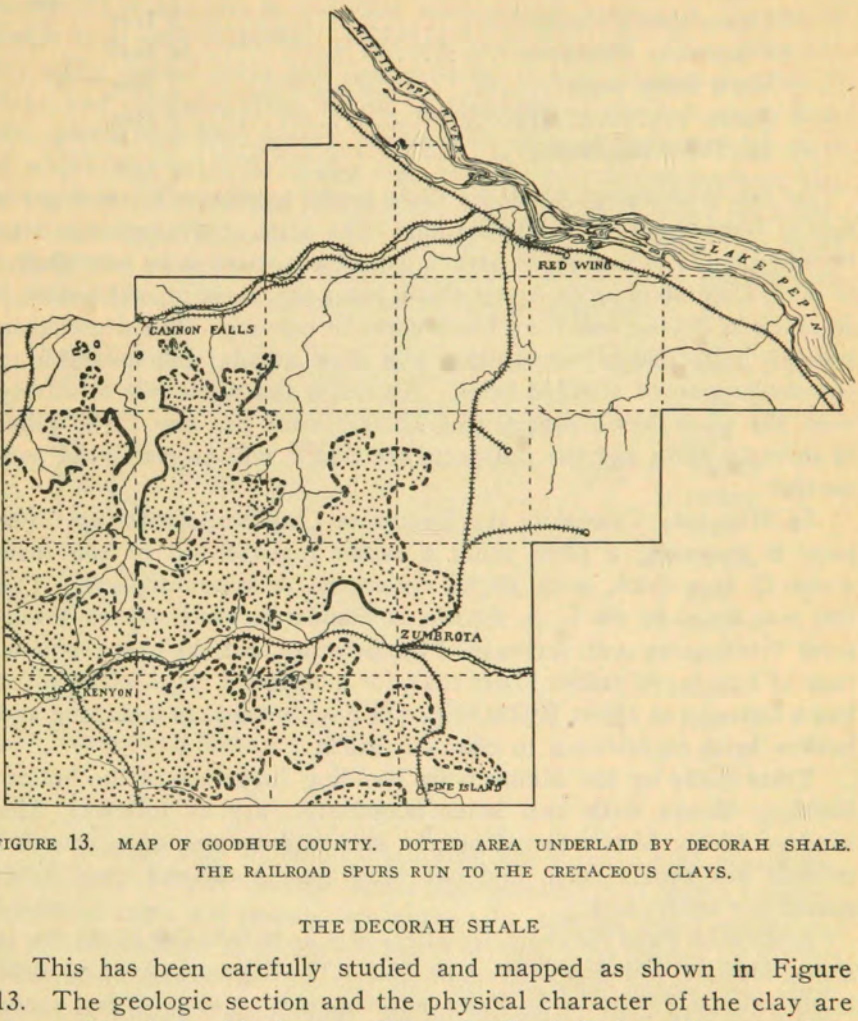


FIGURE 13. MAP OF GOODHUE COUNTY. DOTTED AREA UNDERLAID BY DECORAH SHALE. THE RAILROAD SPURS RUN TO THE CRETACEOUS CLAYS.

THE DECORAH SHALE

This has been carefully studied and mapped as shown in Figure 13. The geologic section and the physical character of the clay are almost identical with those at West St. Paul, Dakota County. The clay is being used at Zumbrota and Wanamingo, and a company is being organized to develop the shale at Cannon Falls. At Wanamingo the following geologic section was exposed:

Surface loam and loess	4 feet
Green shale	4 feet
Limestone	10 inches
Limey green shale	3 feet
Platteville limestone	14 feet
Hard limey shale	2 feet
Shale	3 feet
St. Peter sandstone	

At the Wanamingo plant the shale seems to require a few degrees higher temperature for vitrification. The clay at Wanamingo was tested by the U. S. Bureau of Standards and was found to be very similar to other Decorah samples, except that it had a somewhat greater tendency to crack in drying and form black cores in burning. The decrease in porosity with rise in temperature was slow, steady, and favorable to the production of vitrified brick. Although the deposit is relatively thin, the plant has a capacity of 120,000 brick per day. The plant is recently built, and the prospects are that it will be eminently successful.

In Minneola Township, the Zumbrota Clay Manufacturing Company is operating a plant using a rather massive bed of the shale some 15 feet thick, with slight variations in different parts. The clay was tested by the U. S. Bureau of Standards, which reports a uniform vitrification with increase of temperature, but the best temperature of burning is rather lower than for most good clays. The plant has a capacity of about 50,000 brick per day, but makes drain tile and hollow brick in addition to common brick.

Tests made by the Minneapolis Building Inspector of the hollow building blocks with two holes lengthwise, are as follows: The average of six blocks tested on the side and on the edge was 330 pounds per square inch, and one block tested on end gave 5,100 pounds per square inch.

At Cannon Falls the character of the clay as to behavior in the fire is almost identical with that at West St. Paul. The exposures in all of these localities extend from the St. Peter sandstone upward some 40 feet above the Platteville limestone, after which a mantle of glacial drift of varying thickness is found.

CRETACEOUS CLAYS

The stoneware and sewer pipe factories at Red Wing have become justly famous from their high-grade products and derive their most excellent clays from two occurrences a few miles south along the Great Western Railroad. The best known of these is at Clay

Bank, about 13 miles south of Red Wing. According to F. W. Sardeson[1] this clay illustrates a remarkable case of transportation by glacial ice of a large mass of bed-rock formations. The clay as opened in the pits is underlaid with gravelly drift and the stratification is greatly disturbed, crumpled, and irregular. (See Plate III, B.) The usable clays are separated by layers of sand and sandy clays, and careful sorting has to be done during the process of mining. For a long time several grades were shipped from the pit, some of which was used for sewer pipe and the rest for stoneware, but, as the material has been found to be very limited, a plant for washing the lower grade, darker colored clay has been installed to make it fit for the higher priced stoneware. The complexity of the deposits where locally exposed is indicated in the following section:

Surface drift	1 to 3 feet
Gray clay	4 feet
Sand	1 foot
Clay	12 to 14 inches
Sand	8 inches
Gray clay	6 feet
Sand	10 inches
Clay	1 foot
Sand	2 feet
Clay	14 feet
Sand	1 foot
Clay	1 foot
White sand-bottom	10 feet+

PROPERTIES

The average clay slakes in 3 minutes, has a fairly high plasticity and requires 34 per cent of water for molding. It has a tensile strength of about 100 pounds per square inch, whether dried rapidly or not. The shrinkage on drying is about 6 per cent. As burned by the U. S. Bureau of Standards, the clay has the following properties: The color ranges from buff to gray during burning. The clay becomes hard at about cone 010 (1742° F.), and softens at about cone 20 (2786° F.). This is a remarkable range, but the porosity at no time was found to fall below 6 per cent in the best grade of clay. The temperature recommended for burning is about cone 5 (2246° F.). The second grade of clay from the same pit, which is usually washed

[1]Sardeson, F. W., The so-called Cretaceous of southeastern Minnesota: Jour. Geol., Vol. 6, p. 679.

before using in the stoneware plant, behaves very much the same; but without washing, it burns to a lower porosity and has nearly an equal range of vitrification. The third grade of clay, used only for sewer pipe, is much like the latter. As burned at the University the clay is found to become hard at cone 010 (1742° F.), and reaches viscosity at about cone 10 (2426° F.). It is cream-colored or buff at higher temperatures. Analyses are reported in Table II, page 45.

At Belvedere, half a mile east of Belle Chester, a new deposit of Cretaceous clay recently has been developed, and its success may be taken as an indication that still other deposits of such excellent clay may yet be brought to light. This deposit was discovered by careful prospecting and observation of fragments in the drift followed by careful drilling before any excavation was undertaken. It will average 10 feet in thickness, ranging from 1 to 25 feet over an area of 40 acres. Its appearance is similar to that at Clay Bank and its origin is assumed to be the same. The deposit is capped by 3 to 6 inches of ferruginous sandstone, and below it is a similar sand rock apparently of Cretaceous age, though its crumpled condition would indicate transportation by glacial ice. This is the deposit now used by the Red Wing Sewer Pipe Company, though a part of it is of sufficiently high grade to be selected for the stoneware factory. The Red Wing Sewer Pipe Company has two plants at Red Wing and one at Hopkins, near Minneapolis. (See Plate VII.) In addition to the production of sewer pipe they manufacture a few vitrified drain tile and other specialties. Their capacity is 35,000 car loads per year.

Tests by the U. S. Bureau of Standards are as follows: The best clay at Belle Chester is satisfactory in plasticity and molding properties and requires 21 per cent of water for molding. It shrinks 7 per cent on drying and does not crack. The color of the burned clay is buff at low temperatures and gray at higher ones. The porosity decreased from 29 per cent at cone 010 to 20 per cent at cone 02 and 10 per cent at cone 5. It softens at cone 20, and is therefore not highly refractory.

Second-grade material from the same pit as tested by the Bureau of Standards showed much the same behavior, but softened at cone 18 and, when burned at medium temperatures, showed a green efflorescence.

While these two localities are the only ones of commercial value now known, traces of the clay are seen at numerous places in the drift in the form of fragments, streaks, pockets, and thin lenses. "Ironstone" fragments similar to the ferruginous shale layers associated with the clays at Clay Bank and Belle Chester, are also frequently found in the drift. These indications of clay seem to be most numerous northwestward from the deposits now being worked. There are strong possibilities that systematic prospecting with drills or augers will result in the discovery of other isolated areas of Cretaceous clay in the eastern part of the county.

RED WING STONEWARE TECHNOLOGY

The clay is mined by hand digging in benches and vertical sided rectangular pits. It is loaded directly on to the cars for shipment to Red Wing, or to Minneapolis. The factory at Red Wing has produced stoneware since 1872. This plant now uses 75 tons of clay per day. Clays for glazing are obtained from the southern states, but it is possible some suitable slip clay may be found in this State.

Clay from the pit is shipped by rail to the plant where it is unloaded into bins. Several grades of clay are recognized, some of which are so pure as to require no preliminary treatment, but the bulk of the clay for the manufacture of stoneware is first subjected to a washing process to remove sand and other impurities. This clay is all reduced to a slush in blunger mills and passed through rotary sieves or lawns (80-mesh) and then run into large settling vats or cisterns. Live steam is used in the blunger mills and throughout the washing process, and the slush is kept almost to the boiling point to facilitate the washing and pressing. The coarser sand and impurities are removed in the rotary sieves or sifters. The slush is then pumped into large filter presses where the water is strained out and the clay is pressed into the form of cakes weighing about 40 pounds each. The filter cakes go to the mill room and are tempered in pug mills. The clay is then loaded on small trucks and distributed around to the various benches in the plant ready for the skilled workmen to mold. The molded pieces go to tunnel dryers where they are kept for 36 hours, and the moisture removed. When the ware comes from the dryer, it is finished and glazed and is then ready for the kilns. The ware is burned at a temperature of about 2200° F., and the heat is maintained from 45 to 60 hours, depending upon the product desired. It requires nine days from the first process of preparation until the product is finished.

The quality of the ware made at Red Wing is excellent. As compared with the stoneware and sewer pipe produced in other localities, it is found that the temperature of fusion is rather lower than the average, but the range of vitrification (over 700°) is so great that the product is not at all to be condemned on account of the low temperature of burning. Its vitrification and strength may be fully equal to that burned at higher temperatures.

OTHER CLAYS

A deposit of gray drift has been explored by the Red Wing Sewer Pipe Company near the village of Goodhue in Sec. 10, in the hope that it will be available as a plastic bond for mixing with the Cretaceous sewer-pipe clay. The deposit is 20 feet thick and covers 80 acres. It is dark brown to yellowish in color and is covered with 4 feet of sand and soil. Although it is to be classified as glacial drift, it is remarkably free from pebbles, and may be composed of debris from Cretaceous deposits over which the ice passed. The clay slakes in 1 minute, is very highly plastic, and requires 26 per cent of water for molding. The tensile strength is well above 50 pounds per square inch, but the brick is considerably weakened by rapid drying. It would have a good effect in increasing the strength of a non-plastic sewer-pipe clay. Its air shrinkage is 9 per cent. Burning tests are as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
07	Red	3	3
05	Red	4	10
1	Red	7	4
2	Red	8	......
5	Red	......	13

The clay burns hard at cone 07 (1850° F.), and becomes viscous at about cone 8 (2354° F.). Having thus a range of vitrification of 500 degrees, it may be safely used for vitrified ware, such as sewer pipe, for which it is recommended. Some preliminary experiments by the Sewer Pipe Company have resulted rather unfavorably. Possibly the mixture of the two clays may not behave as well as would be indicated by either one alone, but the U. S. Bureau of Standards reports very favorably on a mixture of ⅔ Cretaceous sandy clay and ⅓ this clay.

Cone No.	Color	Porosity
011	Pink	24
05	Buff	17
02	Buff	15
2	Gray	10

The mixture would be better for making sewer pipe than either clay alone.

At the town of Pine Island the loess is exposed to a depth of 5 or 10 feet over a very large territory. The deposit was worked up to about 6 years ago, and produced a fair quality of red brick, but there is not much local demand for the product.

Two miles from Vasa is a sandy alluvial clay along Belle Creek, rather favorably exposed, but apparently too sandy to make a good grade of brick. A few kilns were burned about 50 years ago, and the brick seem to have stood the test of service, but the sample taken was so sandy and weak that it could hardly have been possible to pile the brick into a kiln. This may not have been representative material.

At Frontenac, also in this county, John Bartron has a deposit of alluvium along Wells Creek a considerable distance from the railroad. It is known to be over 4 feet thick. An analysis made for Mr. Bartron by F. F. Grout, is as follows:

Analysis of Clay at Frontenac

Silica	63.32
Alumina	12.68
Iron oxides	2.66
Lime	5.08
Magnesia	3.94
Moisture	1.83
Ignition	8.47
Alkalies, etc., by difference	3.02

Sand-lime brick are manufactured at Red Wing. The lime is shipped in from Iowa and the sand is taken from a hill of modified glacial drift near the factory.

GRANT COUNTY

Types of clay, 2. Recent ....Lake clays
1. Pleistocene ....Gray drift

Gray drift covers most of the county and an attempt made to use it at Elbow Lake was not very successful. Along the shores of Pelican Lake are clays of another type which may be worthy of development.

HENNEPIN COUNTY

Types of clay, 3. Recent ....Alluvium
2. Pleistocene ....b) Lake and river clays
a) Red and gray drift
1. Decorah shale

At Minneapolis the glacial river clays have been developed on the north side of the city, for cream brick, pottery, and fire-proofing, for which there is still an abundant supply, but the value of city property tends to crowd brick works northward into Anoka County. Detailed discussion of the clay is given with those of Anoka County. The pebbly gray drift of the county, and recent alluvium along the Mississippi River, cannot well be used in competition with this deposit. The red drift is in most places deeply buried. Swamp clay was used at Hanover and gray drift was once used at Rogers, but the operations were not successful. The Decorah shale is mostly eroded, partly buried, and occurs in property more valuable for city lots than for development of clay. The excellent qualities of the glacial clay used are shown by large industries developed here and in Anoka County, just to the north.

Mention should be made of the sand-lime brick factories at Minneapolis.

HOUSTON COUNTY

Types of clay, 3. Pleistocene loess
2. Decorah shale
1. St. Lawrence formation

The shales of the St. Lawrence formation outcrop in many bluffs, but have no value at the present time.

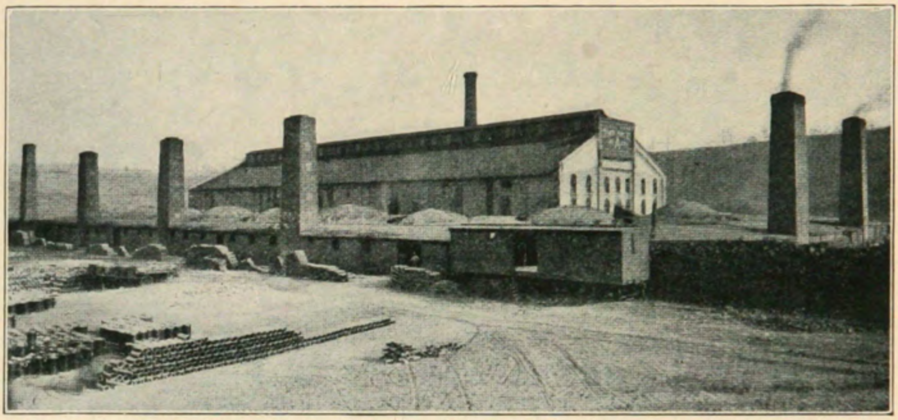
The Decorah shale occurs in the extreme southwestern corner of the county. It can best be developed in the vicinity of Spring Grove where good outcrops were seen, but proved to be rather thin. A mantle of loess covers most of the county.

There were no brick yards in operation in the county in 1912, but old plants were located in former years at nearly every town in the county,—Money Creek, Spring Grove, La Crescent, Houston, and at other localities. Common red brick can be made from the loess at nearly any locality in the county.

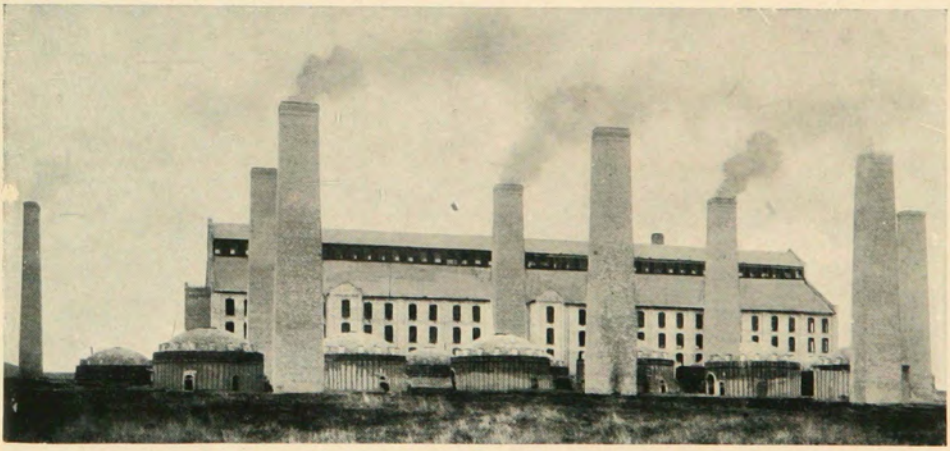
HUBBARD COUNTY

Types of clay, 2. Recent ....Lake clays
1. Pleistocene ....Gray drift

Near Akeley, a mile and a half from the Great Northern Railroad, a plant has been operating on a deposit evidently formed in the bed of a lake which may be at least partially of glacial age. The deposit is known over an area of 80 acres and at places is 40 feet thick. The upper half of the deposit is yellow and the lower half blue-gray, but both parts burn to cream-colored brick except a few inches at the top from which the lime has been leached. At the plant the production is about 200,000 stiff-mud cream-colored brick per year.



A. FACTORY "A"—RED WING SEWER PIPE CO.



B. THE MINNEAPOLIS SEWER PIPE WORKS. A MODERN FIRE-PROOF FACTORY.

Gray drift was used a few miles from Park Rapids, but the plant has not been active since 1894. The clay is said to be fairly free from limestone, and work was stopped because the market was small and the funds were not sufficient to tide the company over ill times.

ISANTI COUNTY

Types of clay, Pleistocene ....b) Gray lake and river clay
a) Gray drift

At Cambridge and elsewhere along the Rum River, gray laminated clay was used for many years, beginning in 1881. The clay is now exposed for 20 feet, but is overlaid in the bluff with about 25 feet of sand. It could be profitably worked for only a small area where the overlying sand has been at least partially eroded. The clay slakes at once and shows fairly high plasticity, requiring 29 per cent of water for molding, and shrinking 7 per cent on drying. The clay becomes hard at cone 04 (1958° F.), at which temperature it is salmon-colored, shows a shrinkage of 2 per cent and an absorption of 23 per cent. It reaches viscosity at cone 2 (2138° F.). A local plant manufactured salmon brick from this laminated clay, but the work has been abandoned. A high proportion of sand was used in tempering, and was obtained from the overlying bed. The addition of 50 per cent of this sand raised the temperature of vitrification slightly, but did not change the general character of the product.

One or two attempts were made to use the gray drift, but they met the usual difficulty.

ITASCA COUNTY

Types of clay, 4. Recent...........Lake clays
3. Pleistocene........c) Lake and river clays
b) Gray drift
a) Red drift
2. Cretaceous
1. Huronian.........Paint rock, etc.

No clays were worked in this county up to 1900. Since then the development and activity on the iron ranges have led to the use of some clays in the southern part of the county—the glacial lake or river clays at Verna and Grand Rapids. The deposit near Verna is the more promising. The Verna Brick Company has opened a deposit of laminated clay near the station of Warba on the Great Northern Railroad. The deposit which is considered available is about 10 feet thick, and extends over about 10 acres. It is yellow in color, and apparently has been leached. Underlying it and extending over a great many acres of the surrounding country is a blue laminated clay with a few limestone pebbles, which in some well records is reported to be more than 60 feet thick. The yellow clay burns to a cream-colored product, while the blue clay is said to burn red and show a much greater shrinkage. Any attempt to mix the blue and yellow clays meets the usual difficulty in mixing a stiff, plastic clay with a lean, more sandy one. The plastic lumps remain suspended in the more fluid mass and a great amount of pugging or some other form of mixing is necessary, if one would avoid a defective structure resulting from auger laminations. The yellow clay which is being used slakes at once, and shows very low plasticity, requiring 23 per cent of water for molding. The air shrinkage is 3 per cent and the tensile strength is well above 100 pounds per square inch even after rapid drying. Burning tests gave the following:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
03	Buff	1	30
01	Buff	4	23
3	Greenish buff	......	......

The clay becomes hard at cone 02 (2030° F.) and reaches viscosity at cone 3 (2174° F.). The plant which is operating at this point has a capacity of 35,000 brick per day and makes a common brick of cream color. Wood is the most available fuel.

At Grand Rapids bricks were burned from a very sandy laminated clay, which was discovered along the banks of the stream at the northeast edge of town. This clay is yellow in color, and seems to be very sandy when dry. It slakes in 1 minute, and its plasticity is very low. It requires 21 per cent of water for molding and has a shrinkage of 3 per cent on drying. The tensile strength is over 130 pounds per square inch, but the adhesion test indicates that it would not work well in the auger machine. Burning tests gave the following results:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Red	1	21
03	Brown	4	13
1	Brown	5	10
3	Brown	......	......

The clay burns too hard to be scratched by a knife at cone 02 (2030° F.), and becomes viscous at cone 5 (2246° F.). In two attempts at brick making soft-mud machines were used and in another, a stiff-mud machine.

None has been particularly successful, and work has ceased. Shipping conditions are not very favorable.

Cretaceous shales have been reported[1] to outcrop along Deer River, River erosion had cleaned off these deposits and left them with smooth polished surfaces, which are more resistant to erosion than the glacial drift. It was generally assumed that the limey concretions were rare occurrences in the Cretaceous. In the present investigation, a somewhat hasty examination revealed no outcrops except those containing a considerable number of lime concretions or pebbles. On the Big Fork River, two miles below the mouth of Deer River, blue clay outcrops near water level. It is sticky and tough but is not readily accessible and it is so near the water level that it would not be profitable. Similar outcrops occur on the Big Fork River 2 miles above the mouth of Deer River.

Half a mile above the mouth of Deer River, which is about half way to the first dam on Deer River, 4 to 6 feet of clay is exposed for 50 feet along the bank. It probably is connected with another outcrop close to the mouth of the river. The clay is laminated with alternately light and dark blue layers. It is covered with about 10 feet of glacial drift and contains a few rounded pebbles. This deposit is rather more accessible than the last two mentioned, and it appears to be the best clay discovered in this region. Its plasticity is high and 34 per cent of water is needed in molding. The shrinkage on drying is about 9 per cent. Tested by the Minnesota School of Mines Experiment Station, it showed the following properties:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
04	Salmon	......	15.0
2	Salmon	......	0.5

The clay was undeformed and too hard to scratch with a knife, at both these temperatures. It has a good range of vitrification. Slow heat is needed to avoid black cores.

The mantle of gray drift over the county is largely modified and sandy, but the surface of it is irregular and small lakes abound. Clays have accumulated in these lake basins, probably beginning in glacial times, but continuing to the present. The character of this type of deposit is indicated by the clay at Lilly Lake south of Grand Rapids. Numerous test pits and borings have revealed deposits of clay and irregularly interbedded sand, which seem to be of excellent quality for common brick. The clay slakes in 3 minutes, shows fairly high

[1]Grant, U. S., Final Rep., Minnesota Geol. and Nat. Hist. Survey, Vol. 4, p. 183.

plasticity, requiring 28 per cent of water for molding. Its air shrinkage is 7 per cent and it checks considerably even when carefully dried, so that its tensile strength is usually less than 50 pounds per square inch. Burning tests are as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Salmon	3	17
04	Salmon	4	15
01	Red	8	3
1	Red	9	3
2	Red	9	2

The clay becomes hard at cone 05 (1922° F.), and reaches viscosity at cone 2 (2138° F.).

At Coleraine, the paint rock of the iron-ore formation is especially troublesome in the mines and is over 20 feet thick. It is all moved in getting the ore and, if a little care were used to keep it free from ore and the sandier layers of taconite, it is capable of being used for red brick, though not safely for a hard vitrified product.

At Pengilly, a particularly sandy phase of modified drift occurs over a large area and a sand-lime brick plant just erected has every chance of being successful if the necessary precautions are used to keep the product up to the high grade possible.

JACKSON COUNTY

Types of clay, 2. Recent...........b) Lake clay
a) Alluvium
1. Pleistocene........Gray drift

Brick and tile are manufactured from gray drift at the town of Jackson where a yellow clay with very little limestone or other impurities extends over 14 acres and has a depth of 15 feet. The deposit is close to the Milwaukee Railroad and conditions seem to be favorable for the development of a considerable industry. This is the plant which has developed the dry process of separation of limestone from the clay. The pit is carefully kept dry, and the clay is plowed over a considerable surface and gathered up only after the wind and sun have dried it pretty thoroughly. It is then transferred to sheds for further drying, with protection from rain. The crushing is done in a modified dry pan from which an elevator carries the clay to a screen. The limited space in the shed room greatly limits the capacity.

At Okabena, a similar deposit has been explored and two small plants for making hand-molded brick were built to make use of it. This clay has the common qualities and defects of the gray drift.

At Jackson, along the flood plain of the river, there is a deposit of clay of about 20 acres in extent, known to be 5 feet thick. It was developed about six years ago, and the product was used in several buildings in Jackson. Its working and burning properties seem to be excellent, but there are a few limestone pebbles which have caused difficulties. Blue clay is said to lie below it.

At Heron Lake, along a gentle slope on the northwest shore of the lake, there is a yellow laminated clay, probably partly of glacial origin, but also in part post-glacial. The deposit covers about 100 acres and has a thickness of 12 feet. The laminae are of variable thickness and many of the vertical joints are stained with iron. Except along the lake, the deposit is surrounded by pebbly gray drift.

A. V. Bleininger[1] reports the following tests: A glacial calcareous clay from Heron Lake possesses good plasticity and working properties, though it is somewhat too fine-grained for drying when made into larger pieces.

Specific gravity powdered dry clay = 2.654.

Linear shrinkage in per cent wet length = 7.72.

Mechanical analysis by elutriation gave:

	Raw clay	After heating to 300°
Coarser than 120-mesh	1.72	9.51
Average .577 mm. in diameter	0.98	3.29
Average .0354 mm. in diameter	8.03	5.57
Average .0167 mm. in diameter	9.03	4.44
Average .005 mm. in diameter	80.24	77.17

After a heat treatment of from 250° to 400° C., the plasticity is found to be lower, and the air shrinkage is greatly decreased. The decrease is greater, the higher the temperature of preheating.

Our sample evidently was not improved by preheating, for the raw clay showed no more cracking than the preheated clay, and was as good as the other clays studied after preheating. The effect of preheating on fineness of grain explains some of the variation found in plasticity and shrinkage.

An enterprising company operating at Heron Lake produce hollow brick and tile. They have been at work since 1890, and make use of a number of down-draft kilns with a capacity of about 80,000 brick per day. The product is cream-colored if burned hard, but salmon at lower temperatures. They find that the deposit is best suited for the manufacture of hollow brick and tile. The fusion is so sudden that the products are seldom vitrified.

[1]Bleininger, A. V., Preheating clays: U. S. Bureau of Standards, Vol. 7, No. 2.

KANABEC COUNTY

Types of clay, 2. Pleistocene........b) Gray lake and river clays
a) Red drift
1. Algonkian (?)....Red clastic series

At Mora, an attempt was made to use the shale of the red clastic series for terra cotta. Wells show a considerable extent of the shale below the drift, but it is rarely over 10 feet thick. It is exposed in Sec. 1, T. 39 N., R. 24 W. for about 100 yards along the river where it is about 3 feet thick. The clay slakes in 2 minutes, and is very plastic, requiring 22 per cent of water for molding. Its air shrinkage is 5 per cent. Burning tests are as follows:

Cone No.	Color	Per Cent Fire Shrinkage	Per Cent Absorption
06	Red	0	17
2	Red	2	14
5	Red	2	......
12	......	......	Melted

It becomes hard at cone 06 (1886° F.) and was undeformed at cone 5 (2246° F.). The range of vitrification is over 360° F.

An attempt was made to use the ferruginous shaley sandstone near by, but, as now exposed, it contains very little clay and it does not bond at all.

Yellow laminated clays outcrop in the bank of the river at the northwest side of the town of Mora. The deposit apparently extends over many acres and was sampled to a depth of 6 feet with an auger which did not reach the bottom. It appears to have rather numerous concretions of a limey nature, and the working qualities of the sample are not good. Its shrinkage on drying was over 13 per cent, and upon burning it checked and showed still further shrinkage. It can hardly be recommended for any purpose.

At several other points in Kanabec County, attempts have been made to manufacture brick from glacial clays some of which are the laminated lake clays. One plant was installed east of Rice Creek on the road from Brunswick to Grasston. The clay includes some sandy layers as much as 6 inches thick. It slakes at once, and is fairly plastic. It has an air shrinkage of 8 per cent, becomes hard at cone 05 (1922° F.), and reaches viscosity at cone 2 (2138° F.). If this deposit was favorably situated as to the market, it might be profitably worked.

KANDIYOHI COUNTY

Types of clay, Pleistocene........b) Gray lake clay
a) Gray drift

The laminated clays will form the chief clay resources of Kandiyohi County, though gray drift is abundant. A little over a mile west of Willmar, along the Great Northern Railroad, is a deposit of laminated clay known to extend over about 25 acres. It consists of yellow oxidized material for 15 feet, under which is at least as much blue clay. In the yellow clay are a few limestone pebbles or concretions. The blue clay is as usual more plastic than the yellow and shows greater shrinkage when used alone. Both the yellow and the blue clay will burn to a cream color at high temperatures, but are salmon-colored if under-burned. The Willmar Brick Company has been at work here for 20 years, making about 2 million stiff-mud cream brick each year. On the northwest side of Nest Lake another plant made use of a similar clay.

The county contains many lakes and marshes and many of these may be underlaid by alluvial clays.

KITTSON COUNTY

This county is no doubt supplied with such clay as is used at Grand Forks and at Winnipeg—the silts of the Red River Valley. Wells report it 136 feet deep and it is no doubt usable to as great a depth as at Grand Forks.

KOOCHICHING COUNTY

Types of clay, 2. Recent...........Alluvium
1. Pleistocene........c) Silts of Red River Valley
b) Gray drift
a) Gray lake clay

In the neighborhood of International Falls, the level character of the country is probably due to the erosive action of the waves of the glacial Lake Agassiz. Much of the surface consists of a sticky clay which has been reported to a depth of 40 feet. The upper portion is leached and relatively free from pebbles, but at a depth of 6 feet, limestone pebbles become rather numerous. The clay slakes in 2 minutes and shows a very high plasticity, requiring 29 per cent of water for molding. The air shrinkage is 9 per cent, and there is probably a considerable tendency to crack on drying, even if this is done slowly and with care, for the tensile strength is below 50 pounds. Burning tests gave results similar to those which characterize the gray drift, and it would seem that some method must be applied to remove the coarser gravel before the clay can be safely used. The proportion of such gravel, however, is very much less than in the common gray drift so successfully used at Hutchinson, but it is doubtful if that process will apply with equal success to the clay near International Falls. The success of the Hutchinson process depends, not only upon the removal of limestone, but upon the quality and the mixing of the materials that remain. The gray drift contains approximately 30 per cent of sand which would be caught in a 100-mesh sieve, but this clay in the Lake Agassiz basin shows only about 3 per cent of sand. Deposits of sand are not abundant anywhere in the neighborhood, and it is suggested that those who wish to make use of this clay should experiment with a grinding process rather than with the washing process recommended for pebbly clays elsewhere.

International Falls and the towns near by are developing so rapidly that special efforts should be made to find good clay. One promising sample was sent to the University several years ago from a point 5 miles east of Ranier, in Secs. 34 and 35, T. 71 N., R. 23 W. The sample made excellent bricks and is said to represent a body of clay 9 feet thick and 40 acres in extent.

At Big Falls, southwest of International Falls, the Big Fork River has cut an extensive gorge below the falls which give the town its name. The bluffs for most of the distance reveal a very pebbly blue clay weathered yellow near the surface. A little below the mouth of Sturgeon River, however, on the farm of Mr. Ben. Lind, is an outcrop of different material. It may be one which was mapped by U. S. Grant[1] as a Cretaceous deposit. The section is as follows:

Soil	1 foot
Common pebbly clay of the Lake Agassiz basin	10 feet
Plastic yellowish gray clay	10 feet
Very fine sandy clay	30 feet

This material outcrops for several hundred yards along the bluff and therefore represents a large deposit, though it is somewhat inaccessible in the present state of development of the country. The clay slakes at once, shows a medium plasticity, and requires 28 per cent of water for molding. Its tensile strength is over 150 pounds per square inch, even when it is rapidly dried, and its air shrinkage is 3.5 per cent. The clay burns to a buff-colored brick with a range of vitrification of about 100° F. and reaches viscosity at cone 4 (2210° F.). A sample of the rich clay without the underlying sandy clay showed similar properties, but vitrified at slightly lower temperature.

[1]Grant, U. S., Final Rep. Minnesota Geol. and Nat. Hist. Survey, Vol. 4, p. 183.

In this county several other patches of shale are noted by U. S. Grant.[1] These have now been visited and sampled to determine their quality. At present they are somewhat inaccessible. In Sec. 1, T. 64 N., R. 24 W., in the southwest bank of Little Fork River between two creeks which join the river from the south, are a series of small landslides. The banks of the river have slipped down to the water's edge, exposing a nearly white, smooth clay. This was sampled for a thickness of 15 feet. It could be traced continuously for several hundred paces, and is exposed here and there for several miles. The clay is slightly laminated with alternating layers of white and a light blue gray and has no visible impurities. It slakes in 1 minute, has a fairly high plasticity, and requires 23 per cent of water for molding. Its tensile strength is over 150 pounds per square inch and it is equally strong if rapidly dried. Its shrinkage on drying is less than 4 per cent. Burning tests by the Minnesota School of Mines Experiment Station are as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
06	Buff	0	23
03	......	2	20
01	Buff	3	20
2	Buff	3	20
5	Buff	......	......

The clay becomes hard at cone 03 (1994° F.) and is just reaching viscosity at cone 5 (2246° F.). A few miles down the river in Sec. 15, T. 65 N., R. 24 W., just below Seller's Rapids, similar clay outcrops near water level and was sampled at a point where the river water had washed over it recently. The physical properties of the clay were very much the same as those of the sample just described, except that the air shrinkage was 8 per cent and the color was red at low temperatures and brown above cone 2. Vitrification occurred at slightly lower temperature, from cone 06 to cone 3, a range of about 300° F. These are the best clays in the county.

At Big Falls, a small creek bed passing the west edge of town has cut into irregular layers of sand and clay which overlie the usual pebbly drift of the region. The deposit may be partly leached drift and partly alluvium. If this is as extensive along the creek as it seems to be, it should furnish a local brick supply. The clay slakes in 1 minute, is highly plastic, and requires 20 per cent of water for molding. Its tensile strength is well above 200 pounds per square inch, even when rapidly dried. Its air shrinkage is 4.5 per cent. Burning tests are as follows:

[1]Loc. cit.

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
01	Salmon	1	17
2	Chocolate	......	......
4	Chocolate	......	......

The clay becomes hard at cone 01 and is viscous at cone 4. The range of vitrification is, therefore, over 150° and it can safely be burned hard.

All these clays have the properties of glacial rather than Cretaceous deposits.

LAC QUI PARLE COUNTY

Types of clay, 3. Pleistocene ....Gray drift
2. Cretaceous ....Shale
1. Archean ....Residual clay

Gray drift, somewhat modified near the surface, covers the county, and the Cretaceous shales and Archean clays are found only in wells. At Dawson and southwest, white clay of the appearance of the Archean is met at a depth of 160 feet.

LAKE COUNTY

Types of clay are the red drift and associated lake clays. They have not been used. Possibly some swamps contain clay. The Keweenawan rocks show thin shale lenses, probably of no value.

LE SUEUR COUNTY

Types of clay, 3. Recent ....Alluvium and swamp clay
2. Pleistocene ....Gray drift
1. Cretaceous ....Shale

Near the town of Ottawa are several clay deposits. Half a mile below the railroad bridge over Cherry Creek, is an outcrop of clay lying between the Jordan sandstone and the Shakopee dolomite. It is only 2 or 3 feet thick where exposed, and there is considerable evidence that it is not in a comformable series with the Jordan and the Shakopee, but has been washed in during Cretaceous or pre-Cretaceous times. This is the first sample taken of a type which is widely distributed throughout the Minnesota Valley from Shakopee to New Ulm. The clays are variegated, red, yellow, and white, and occur here and there like stratified sediments unconformably above the Jordan or the Shakopee. Another common occurrence is in large water-worn cavities and fissures. Before the deposition of these Cretaceous clays, the rocks of the Minnesota Valley had been channeled by rivers and other erosive agents into irregular basins, potholes, and hollows from 5 to 25 feet in depth, often partly covered by overhanging walls. These pocket-like cavities are smoothly water-worn. N. H. Winchell has described[1] an instructive section of the Shakopee dolomite and its associated deposits of this clay in a cut near the railroad bridge which crosses the Blue Earth River about a mile above its mouth. He says:

This cut is perhaps 70 feet above the river, the bank of which is composed entirely of rock, the lower portion of which is the Jordan sandstone, and the upper the Shakopee limestone, the latter composing about 20 feet. In general this railroad cut shows a mixture of Cretaceous clay with the Cambrian, the top of the whole being thinly and irregularly covered over and chinked up with coarse drift. The Cambrian is more or less broken and tilted, at least the bedding seems to have been cut out into huge blocks by divisional planes, which, either by weathering or water-wearing, were widened, the blocks themselves being subsequently thrown to some extent from their horizontality, tipping in all directions. The opened cracks and seams were then filled with the Cretaceous clay, which is deposited between these loosened masses, and sometimes even to the depth of 20 feet below the general surface of the top of the rock. The clay sometimes occupies nooks and rounded angles, sometimes sheltered *below* heavy masses of the Cambrian beds. The clay is uniformly bedded, about horizontally, with some slope in accordance with the surface on which the sedimentation took place. But the most interesting and important feature is *the condition of these old Cambrian surfaces.* They are rounded by the action of water, evidently waves. The cavities and porous spots are more deeply eroded, making little pits on the face of the rock; or along the lines of section of the sedimentation planes with the eroded surface, there are furrows due to the greater effect of water. The rounded surface of these huge masses of limestone is coated with a thickness of about a half inch, or an inch and a half, of iron ore, which scales off easily, and is easily broken by the hammer. While this scale of iron ore is thicker near the top and on the upper surface of the blocks, yet it runs down between the Cretaceous clay and the body of the rock.

The sample collected at Ottawa slakes in 2 minutes, is very highly plastic, and requires 31 per cent of water for molding. Its tensile strength is over 100 pounds per square inch even when dried rapidly. Its shrinkage on drying is 8 per cent. Burning tests are as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
06	Red	4	14
04	Red	7	11
03	Red	9	7
1	Red	10	3
6	Red	......	......

The clay becomes hard below cone 07 (1850° F.) and viscous at cone 10 (2426° F.). Analyses are reported in Table III, page 45. Its qualities are thus shown to be so excellent that it may be worth while to search out more deposits of this character to ascertain whether some of them may not warrant development.

[1]Winchell, N. H., Minnesota Geol. and Nat. Hist. Survey, Second Annual Report, p. 178.

Another clay deposit near Ottawa was developed a little over half a mile up Cherry Creek and half a mile from the Northwestern Railroad. Mr. Randall, on whose farm the clay occurs, reports that it was tested for 27 feet without reaching the bottom. It underlies an area of the high prairie east of Ottawa where rocks are not exposed. The geologic section reported by Mr. Randall is as follows:

Yellow clay drift	0-100 feet
White clay	4 feet
Blue clay	8 feet
White clay	4 feet
Fine white sandy clay	Bottom

This clay outcrops in the bed of the creek and there might be some difficulty with the drainage. It slakes in 1 minute, is very highly plastic, requiring 26 per cent of water for molding. It shrinks 4 per cent on drying. Burning tests by the Minnesota School of Mines Experiment Station resulted as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Cream	4	20
02	Cream	5	20
2	Cream	8	14
4	Cream	8	14
13	Gray	......	......

The clay is notably hard at cone 05 (1922° F.), fully steel hard at a slightly higher temperature, and apparently is not even approaching viscosity at cone 13. The Bureau of Standards reported it as behaving like a refractory clay. It may prove to be highly refractory, but it appears to burn dense at moderate temperatures. The following is the average of five analyses máde for the company.

Silica	58.70
Alumina	28.50
Iron oxides	0.18
Magnesia	0.23
Lime	0.69

The St. Paul Fire Brick Company was organized to exploit this deposit and a plant was constructed with a capacity of several million brick per year. No products have been turned out for several years. Probably further work would be successful.

As a third type of clay at Ottawa, the river bluffs, half a mile from the depot of the Omaha Railroad, expose from 50 to 100 feet of gray drift for a considerable distance. A few feet of coarse gravelly drift overlies the bowlder clay which was sampled. The clay slakes in 3 minutes and its plasticity is low. It requires 19 per cent of water for molding and has an air shrinkage of 3 per cent. Its tensile strength is nearly 200 pounds per square inch, though it checks slightly if rapidly dried. Owing to the presence of abundant particles of limestone the product falls to pieces if burned to temperatures below cone 2 (2138° F.). The limestone is so abundant that the clay melts at a temperature a few degrees higher. To make use of this material, it would be necessary to apply some process for removing the limestone pebbles, but as it occurs in the same neighborhood as some apparently high-grade Cretaceous clays, it was thought worth while to call attention to it. A plant making use of one of these clays might easily increase the variety of its product without greatly increasing the expense of an installation.

The gray drift in other parts of the county is not as good as the other clays available. An attempt was made to use it for brick at Waterville, but some swamp clays near by are more promising.

At Le Sueur, the alluvium of the Minnesota River is favorably exposed along the Omaha Railroad. Similar deposits are found at Mankato, and here and there along the Minnesota River. The sample taken slakes at once, has a fairly high plasticity, and requires 28 per cent of water for molding. Its air shrinkage is 6 per cent, and its tensile strength about 50 pounds per square inch. Burning tests gave the following results:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
03	Salmon	0	26
01	Brown	3	20
1	Brown	4	18
2	Brown	7	11
3	Brown	......	2

The clay becomes hard at cone 01 (2066° F.), and reaches viscosity at cone 3 (2174° F.). Soft-mud brick can be produced at the rate of about 10,000 per day. The brick are red in color, and have stood the test of service since 1882 in some of the buildings in Le Sueur.

LINCOLN COUNTY

Gray drift covers the whole area of the county. No deposits were found to be well situated for development. Cretaceous shales are known from well records only.

LYON COUNTY

Types of clay, 3. Pleistocene .... Gray drift
2. Cretaceous .... Shales
1. Archean .... Residuals

The gray drift covers the county, but, owing to its lime content, attempts to use it have failed. At Marshall, where shipping facilities are good, it might be possible to clean the clay. Cretaceous clays within 50 feet of the surface have been discovered by well drilling.

The Archean lies too deep for exploitation.

McLEOD COUNTY

The only clays known in McLeod County are of the gray drift, although some recent lake clays may be present.

The only brick yard in the county is located at Hutchinson, where an excellent quality of brick and drain tile are manufactured from the ordinary gray drift. The glacial drift there is similar to that found over large sections of the State. It contains numerous lime and quartz pebbles, some sand and gravel, and a few large bowlders. The plant here successfully used this material, where many others have failed, because of the special washing process devised by Mr. M. C. Madsen, by which the pebbles and sand and other impurities are completely separated from the clay. This process is of especial importance to those who may be interested in the ceramic industry because it opens a field for the utilization of a vast amount of material which has heretofore been considered valueless. A description of this plant and the methods used is given on page 25.

The upper part of the gray drift at Hutchinson is weathered yellow. (See Fig. 2.) Blue-gray clay of equal value lies at depths greater than 16 feet. The extent of the deposit is to be measured in scores of square miles, and the over-burden at many places is but a few inches of soil. The clay slakes in 5 minutes, is fairly plastic, and requires 24 per cent of water for molding. Its tensile strength is nearly 100 pounds per square inch and over 75 pounds when it is rapidly dried. The following analysis is in the records of the company, and was made on washed material.

Analysis of Washed Gray Drift, Hutchinson

Silica	48.25
Alumina and iron oxides	36.60
Magnesium carbonate	0.70
Calcium carbonate	1.49
Alkalies	4.46
Loss on ignition	8.50
	99.00

A second analysis stated below was furnished by Mr. M. C. Madsen, manager of the company, to Professor Ries, of Cornell University.

Silica	60.31
Alumina	23.77
Ferric oxide	7.96
Lime	2.50
Magnesia	1.75
Alkalies	242
Water	...
	98.71

These two analyses, though varying widely, probably represent only a difference in the thoroughness of washing, and both clays seem to be capable of yielding a high-grade product. The washed clay, burned by the Minnesota School of Mines Experiment Station, gave the following results:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
06	Salmon	......	......
05	Salmon	1	24
03	Salmon	2	23
1	Yellow	7	9
3	Yellow	8	8

The clay burns too hard to be scratched with a knife at cone 06 (1886° F.) and becomes viscous at cone 3 (2174° F.), thus having a range of about 300°. It can be safely burned to a very hard product. Tests made on common brick by the Experimental Engineering Department of the University of Minnesota show an average crushing strength of 2,834 pounds per square inch. The particular advantage of the drain tile here produced is that they resist frost exceedingly well. To obtain further details of its physical character, the clay as used at the plant was washed through a series of sieves. The proportion of sand to clay as determined by what passed the 20-mesh sieve and what passed the 100-mesh sieve, was 30 to 70. It is thought that closely similar gray drift wherever found to contain about 30 per cent of sand, would be suitable for the application of the Hutchinson process of treatment. Samples were taken from about a dozen widely separated places, and in most of those from which the washed clay showed 30 per cent of sand or a close approach to 30 per cent, the mixture of sand and clay burned to a product almost identical with that from Hutchinson. It is therefore safe to say that throughout at least half the State this material is available for the production of high-class brick and tile at a commercial profit unless some purer clay is available in the same region.

MAHNOMEN COUNTY

Pleistocene gray drift covers the county except where recent swamp deposits occur. These latter may prove to be worth investigation, but are not as numerous as in counties near by.

MARSHALL COUNTY

The silts of the Red River Valley overlie the gray drift in much of this county. North of Warren, the clay along the river has been used for many years. It is known to extend over 100 acres and the following section is characteristic:

Black soil	6 inches to 1 foot
Yellowish to brown pebbly alluvial clay	10 feet to 15 feet
Yellowish to gray stratified sand with pebbles	10 feet
Hard, blue, plastic, smooth clay	Depth unknown

The first 4 feet are almost free from pebbles and are used for soft-mud, cream-colored brick when there is a demand. The underlying blue clay was tested at the plant and is reported useless for common brick.

MARTIN COUNTY

Companies with capital invested have sought and offered prizes for the discovery of good clay here, without success. A fine silty clay of doubtful origin, suitable only for hand molding, is found at Granada. Surface loam was used for brick on the south side of Buffalo Lake, but they were not of good quality. The remainder of the county is covered with gray drift, and this is usable only if the lime pebbles can be economically removed.

MEEKER COUNTY

Types of clay, Pleistocene ....b) Gray lake or river
a) Gray drift

Near Litchfield and Kingston, brick yards operated for years on some laminated clays apparently formed in basins in the ice. Limey concretions occur in certain layers. The gray drift north and west of Litchfield consists largely of clay, but is somewhat pebbly. South of Watkins, the gray drift is very widespread, but would require the usual cleansing treatment before successful use could be made of it. An attempt to use the clay without these precautions failed.

MILLELACS COUNTY

Types of clay, 2. Recent.................Lake and swamp clay
1. Pleistocene.............b) Gray lake and river clay
a) Red drift

At the station of Brickton, just north of Princeton, a group of brick factories producing about 15,000,000 brick per season are at work upon a deposit of typical laminated clay. Under the soil there is a superficial layer of clay rarely over 4 feet thick which has lost its laminated structure and apparently has been leached of its lime content so that it burns red. Below this there is 10 feet of yellow clay, followed by 10 feet of gray clay. All of these varieties of clay are usually worked together, mixed in the same proportion in which they are found. Below the gray clay which is being worked, is a considerable thickness of a rich joint clay, which is reported as having a greasy character, but has too much of a tendency to crack on drying to be satisfactorily used. Wells drilled through this find a water supply in gravel and sand which lies just below the joint clay. As is usual in such deposits, the sand occurs in pockets or irregular streaks throughout the deposit. In some pits all of the clay owned by the company may be better adapted for soft-mud brick than for the stiff-mud product which is easily made by the other companies. The main product is manufactured with stiff-mud machines and some small proportion is made light by a central opening for use as fireproofing. Considerable difficulty is found in auger laminations which weaken the product if the clay is not well mixed. Tests by the U. S. Bureau of Standards showed the following characters: The plasticity is high and the auger machine does not produce serious lamination. The air shrinkage is 6 per cent after 26 per cent of water is used for molding. It retains a high porosity until vitrification begins, and it then fuses suddenly. The burned color is buff to greenish yellow at higher temperatures. The average bricks produced have a crushing strength of over 2,000 pounds per square inch as tested in the Experimental Engineering Department of the University.

The surface clay at Brickton, where weathered and leached, is reported as shrinking 8 per cent on drying, but it fuses about as suddenly as the main mass of clay. It has a good red color when burned.

Nearly all the remainder of the county is covered with gravelly red drift. An attempt was made to manufacture brick from it, at the station of Waukon, on the Soo Line. Here the drift contains fully the average amount of sand and gravel and no attempt was made to remove them or even to crush them very fine. The product made in the one kiln burned was naturally of rather low quality. After the clay is crushed to pass a 40-mesh sieve, it has the following characters. Plasticity is fairly high and the water required for molding is 20 per cent. The air shrinkage is about 5 per cent and the tensile strength about 100 pounds per square inch.

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Red	1	14.0
03	Red	3	10.0
1	Red	6	4.5
2	Red	......	4.0

Clay becomes hard at cone 04 (1958° F.) and reaches viscosity at cone 2 (2138° F.).

In the midst of large areas of red drift in the northern part of the county there are numerous swamps, some of which spread over 40 acres or more. In a few places there are exposures of clay of variable thickness along drainage ditches depending upon the depth of water in the original lake. A sample taken from the west side of Waukon slakes at once and shows a high plasticity, requiring 20 per cent of water for molding. Its tensile strength is about 100 pounds per square inch even when it is rapidly dried and its air shrinkage is 5 per cent. Burning tests are as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Red	0	15.0
04	Red	1	14.0
02	Red	4	9.0
1	Red	6	1.5

The clay becomes hard at cone 05 (1922° F.) and reaches viscosity at cone 1 (2100° F.). This is evidently a type of the lake and swamp clays of the region of the red drift. Most of them would be capable of making a thoroughly hard, satisfactory brick.

MORRISON COUNTY

Types of clay,	3. Pleistocene	b) Gray laminated clay
		a) Red drift
	2. Cretaceous	Shale and conglomerate
	1. Huronian..................	Residual clay

Two or three miles west of Little Falls, Pike Creek has eroded a channel through a deposit of laminated clay which is being utilized at two yards for cream-colored brick. The upper 6 feet of clay has a yellow color, and there is an unknown depth of gray clay below it. As is commonly the case, the gray clay is much more plastic than the yellow and is here called joint clay. Thin layers of the joint clay alternate with the yellow in its lower part and about 2 feet of the unweathered joint clay can be mixed with the 6 feet of yellow clay without causing too much danger of checking. The clay slakes in 3 minutes, is highly plastic, and requires 24 per cent of water for molding. The air shrinkage is 5 per cent and the tensile strength is about 150 pounds per square inch, even when the clay is rapidly dried. Burning tests at the Minnesota School of Mines Experiment Station resulted as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
01	Cream	1.0	30
2	Yellow	2.5	25
3	Yellow	3.0	25
5	Yellow	......	......

The clay becomes too hard to be scratched with a knife at cone 01 (2066° F.) and reaches viscosity at cone 4 (2210° F.). It has been used for nearly 30 years, mostly for soft-mud cream-colored brick, though stiff-mud machinery has been made use of in recent years. Each plant has a capacity of about 40,000 brick per day.

At Bowlus, in this county, the main Two River has cut a channel into laminated clay which appears almost identical with that at Little Falls. The tensile strength of this clay is, however, somewhat injured if dried rapidly. The range of vitrification is less than that at Little Falls, the clay reaching viscosity at cone 1 (2100° F.). The Bowlus Brick and Tile Company was organized two years ago to work this deposit, and is equipped to manufacture about 40,000 soft-mud cream brick per day.

Along the Mississippi River, near Little Falls, there are extensive outcrops of staurolitic biotite schist which yields residual clays. As noted by Winchell,[1] a trap dyke of basic dolerite, about 10 feet wide, crosses the slate diagonally. Clays probably of preglacial age are found on the south side of the dyke where they seem to have been protected from the erosion of water and possibly from that of glacial ice.

A few miles south of Little Falls at the Soo Railway bridge, a similar layer of decomposed mica schist has been exposed and at this point there seems to be no harder rock to serve as protection, but the decomposition is general and the resulting clay is very extensive under the drift. It may be followed 100 yards along the river and is visible on both sides. Auger borings showed it to be over 6 feet thick, becoming only slightly harder at that depth. It is probably many feet to solid rock. The clay still contains a large amount of partly decomposed mica, but decomposition has gone so far that the clay is waxy and plastic and can easily be molded. Still farther south near the mouth of the Little Two River, the same sort of material is exposed at the abutment of the bridge on the wagon road crossing the Little Two River. This material once caused great agitation and considerable prospecting for silver on account of the included silvery mica scales. The further extent of similar material is indicated in a report of Warren Upham.[2] At the mouth of the main Two River, a well was sunk through 25 feet of decomposed schist and bored 4 feet farther into the same. All the lumps of rock thrown out crumbled to powder within a few weeks after exposure to the weather. The dry clay slakes at once and requires 33 per cent of water for molding. It shrinks 5 per cent on drying. It burns red, but remains soft up to cone 6 (2280° F.) and is past viscosity at cone 12 (2500° F.). It can hardly be considered satisfactory for vitrification, but is more refractory than the common drift and recent clays.

In the banks of the Mississippi River, 2 miles east of Bowlus, at the road bridge on the road from Bowlus to Royalton, near the clay just described is an outcrop of white clay. This is a bed about 10 feet thick which dips slightly to the south where it is overlaid by Cretaceous shales. A few hundred yards north of the outcrop where one might expect the same clay to occur higher in the bank it has evidently been eroded and the Huronian residual clays outcrop

[1]Winchell, N. H., Minnesota Geol. and Nat. Hist. Survey, Final Rep., Vol. 2, p. 596.
[2]Upham, Warren, Minnesota Geol. and Nat. Hist. Survey, Final Rep., Vol. 2, p. 599.

near the mouth of the Little Two River. In the outcrop near the bridge, the texture varies from massive white clay to a highly concretionary, very ferruginous red clay. The two extremes were separately sampled, but were found to behave very similarly. They do not slake when placed in water nor do they develop much plasticity even after grinding. They stand the temperature of cone 13 (2534° F.) without the slightest deformation and without becoming hard, though the ferruginous sample is the harder. They are evidently quite refractory. No use is being made at present of the deposits in this neighborhood. Professor Dodge[1] analyzed the concretionary material and the results which follow give evidence of the presence of bauxite.

Analysis of Concretionary Clay of Morrison County

Silica	19.81
Alumina	52.43
Iron oxides	1.32
Magnesia	1.64
Soda	0.44
Ignition	23.23
	98.87

Just south of the clay described is a shale containing Cretaceous fossils and including a thin layer of lignite. This shale was sampled at a point a few rods above the mouth of Two River near the road bridge over the Mississippi River. It is exposed for a thickness of 10 feet or more and can be traced more than 200 yards along the banks near water level. It is gray and waxy and apparently contains numerous small mica scales. Where exposed, it has very little overburden, but if traced for any distance it would undoubtedly be found to be covered with glacial drift. It dips a few degrees toward the south and is underlaid by the white basal Cretaceous clay just described. The clay slakes in 2 minutes and is not very plastic. It requires 26 per cent of water for molding and shrinks less than 4 per cent on drying. At cone 4 (2210° F.) it is salmon-colored and has just become hard. It reaches viscosity at about cone 10 (2426° F.). This should be of proper quality to serve as a plastic bond for the nonplastic fire clay, which occurs in the vicinity.

[1]Winchell, N. H., Minnesota Geol. and Nat. Hist. Survey, Final Rep., Vol. 2, p. 602.

MOWER COUNTY

Types of clay, 3. Pleistocene .... b) Loess
a) Gray drift
2. Cretaceous .... Shale
1. Devonian .... Shale

At Austin clays that are possibly of Cretaceous age overlie the eroded edges of the Devonian rocks. A quarter of a mile northwest of the depot of the Milwaukee Railroad the Minnesota Farmers' Brick and Tile Company has opened a deposit which varies from 1 to 20 feet in thickness and underlies a large part of a property consisting of 93 acres. Although the clay is described as Cretaceous, it is somewhat modified and disturbed apparently by glacial action, and it is questioned by Sardeson[1] whether it ever was Cretaceous. The color of the clay is variegated and it contains a few pebbles and rocks, especially where most disturbed near the surface. Glacial drift overlies it but is only a few feet thick. The irregular surface on which it rests is composed of sandstone and dolomite with a thin upper layer of blue clay rarely over 6 inches thick. The clay slakes in 3 minutes and has a very high plasticity, requiring 31 per cent of water for molding. It shrinks 7 per cent on drying, and has a tensile strength of about 80 pounds per square inch even when rapidly dried. Burning tests by the U. S. Bureau of Standards resulted as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Porosity
013	Salmon	High	25.0
010	Salmon	High	20.0
08	Salmon	High	9.0
06	Red	High	1.0
03	Red	High	.6

There was a little trouble with checking, but it was not serious. The porosity was low over a considerable range of temperature.

The factory which has a capacity of 60,000 brick per day has been experimenting with different materials available to determine whether or not high-grade products can be produced. Their work has yielded excellent results. The clay commonly burns red, but by mixing in some of the underlying Devonian rock, they have found it possible to produce buff- and cream-colored ware of equally high grade. The Devonian rock alone burns to a lime rather than a clay product. The 6-inch layer of blue clay between the bed rock and the Cretaceous has also been burned, but the deposit is too small to be of value. It does not differ greatly from the main body of clay.

[1]Sardeson, F. W., So-called Cretaceous of southeastern Minnesota: Jour. Geology, Vol. 6, p. 679.

At the northwest corner of the property owned by this company, a clay which seems to be of most excellent quality has been developed by drilling but has not yet been opened. It is at least 20 feet thick and is known to exist over several acres. It is somewhat stratified, and, though it contains some fine grit, it is highly plastic. Only 2 or 3 feet of soil lie above it and no impurities were discovered except a 6-inch layer of sand. The clay slakes in 5 minutes, but requires only 15 per cent of water for molding. It has a tensile strength of over 100 pounds per square inch, and its air shrinkage is less than 4 per cent. Burning tests by the Minnesota School of Mines Experiment Station resulted as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Buff	0.3	10
1	Buff	1.0	9
3	Buff	1.0	9
5	Buff	......	......
13	Gray	......	......

The clay becomes too hard to be scratched with a knife at cone 05 (1922° F.) and is undeformed at cone 13 (2534° F.). It may prove to be highly refractory, but as it burns dense at moderate temperatures, it is more suitable for stoneware or retorts than for fire brick. Probably such Cretaceous deposits may be found elsewhere in the neighborhood by detailed prospecting with augers and drills. An outcrop near Frankford is probably Cretaceous.

The gray drift covers nearly all of Mower County except along the bottoms of the stream valleys. At many places where it is free from gravel and other coarse impurities, it may be utilized for common red brick. The loess is here unimportant. Abandoned brick yards were noted near Frankford, High Forest, and Leroy, where common brick were made from the glacial drift and the loess.

Limey shale and shaley limestone of Devonian age are found at several localities in Mower County, notably near Frankford along Deer Creek and near Leroy along the upper Iowa River in the eastern part of the county. That at Austin is mentioned above. It contains 15 per cent magnesia and 20 per cent lime. Probably none of these limey shales are of value for brick or other clay products since they are nonplastic, sandy, and impure.

MURRAY COUNTY

This county has only gray drift of the usual pebbly type. It has been tested and found identical in its behavior with that used at Hutchinson.

NICOLLET COUNTY

Types of clay, 3. Recent .... Alluvium
2. Pleistocene .... Gray drift
1. Cretaceous .... Shale

In Nicollet County, opposite Mankato, brick are manufactured from clay which seems to be essentially similar to that on the Mankato side, in Blue Earth County. The clay is not continuous over the whole of the river flat, but occurs in patches surrounded by more sandy or gravelly deposits. The plant has a capacity of over 2 million brick per season. Similar clay is found at Judson, several miles up the river on the Nicollet County side.

At St. Peter, where the Northwestern Railroad crosses the Minnesota River, alluvial clay occupies a considerable area. This has the usual appearance and is apparently of the same quality as that found at Le Sueur. It was used 20 years ago for brick to build the asylum at St. Peter, and a similar deposit was developed just across the river at Kasota. Both plants are now closed. The clay slakes at once, and its plasticity is low. Its tensile strength is 150 pounds per square inch and its air shrinkage 4 per cent. Burning tests are as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
02	Salmon	1	25
01	Gray	2	20
1	Brown	6	15
3	Brown	10	7

The clay becomes hard at cone 01 (2066° F.) and reaches viscosity at cone 3 (2174° F.).

Several outcrops of Cretaceous shale are shown on the map[1] of Nicollet County. These are very close to the town of New Ulm, and are apparently similar to those in Brown County. In Sec. 34, T. 110 N., R. 30 W., at Mr. John Heinmann's lime kiln, is an outcrop about 10 feet thick which can be traced by poorer exposures for several hundred yards along the creek. This is a bedded shale underlying glacial drift and containing some small layers of limestone. Its color is variegated. It is quite easily accessible. The clay slakes only to lumps in 10 minutes. It is highly plastic and requires 23 per cent of water for molding. Its air shrinkage is 7 per cent and its tensile strength is over 100 pounds per square inch, but is somewhat less if the clay is rapidly dried. Burning tests by the Minnesota School of Mines Experiment Station are as follows:

[1]Upham, Warren, Final Rep., Minnesota Geol. and Nat. Hist. Survey, Vol. 2, p. 148.

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Salmon	0	14
03	Salmon	1	13
2	Red	......	......

The clay becomes hard at cone 05 (1922° F.) and is still undeformed at cone 2 (2138° F.), if the heating is not too rapid. Organic matter is apparently responsible for the formation of black cores with great swelling and deformation unless time is given for thorough oxidation. Outcrops of similar clays are found here and there for several miles along the north side of the river.

NOBLES COUNTY

The clay found in this county is the gray drift of the usual type. Brick and tile were made at Worthington 20 years ago, but the drift is somewhat pebbly and the clay is not found to be very satisfactory. If market conditions favored it, a plant of the type working at Hutchinson or Jackson might be successfully operated.

NORMAN COUNTY

Half a mile from the town of Ada is a deposit of the laminated clay of Red River Valley. The deposit has been proved over an area of 5 acres and is apparently much more extensive. It is known for a depth of 15 feet by borings which did not reach the botton. It is overlaid by only a few inches of soil. The clay is yellow and weathered for a depth of about 10 feet, and there is one 6-inch sandy layer included in it. Nearly all the brick buildings in Ada were made from these brick and have stood service very well. The plant has not been operated since 1906. The usual differences are observed between the blue and yellow clays, the former being more plastic and requiring more water for molding. The blue clay at this point requires 52 per cent of water for molding and shows a shrinkage of 17 per cent on drying. This water requirement and shrinkage are very large. It is almost impossible to avoid serious cracking during the drying process. It has the further defect of containing so much organic matter as to form black cores and considerable swelling even if heated with great care. The yellow upper part of the deposit is apparently best used without much addition of the blue clay underneath. It shows a fair range of vitrification, reaching viscosity at about cone 3 (2174° F.).

OLMSTED COUNTY

Types of clay,	4. Recent	b) Swamp and lake clays
		a) Alluvium
	3. Pleistocene	b) Loess
		a) Gray drift
	2. Galena	Shale
	1. Decorah	Shale

Red brick have been made from the glacial clays in a number of localities. Nearly every town of any size in the county has a deposit of clay from which a fair quality of common brick could be made. The most important clay formation in the county is the Decorah shale. This has never been utilized, but in the future it is to this formation that attention should be given rather than to the in-

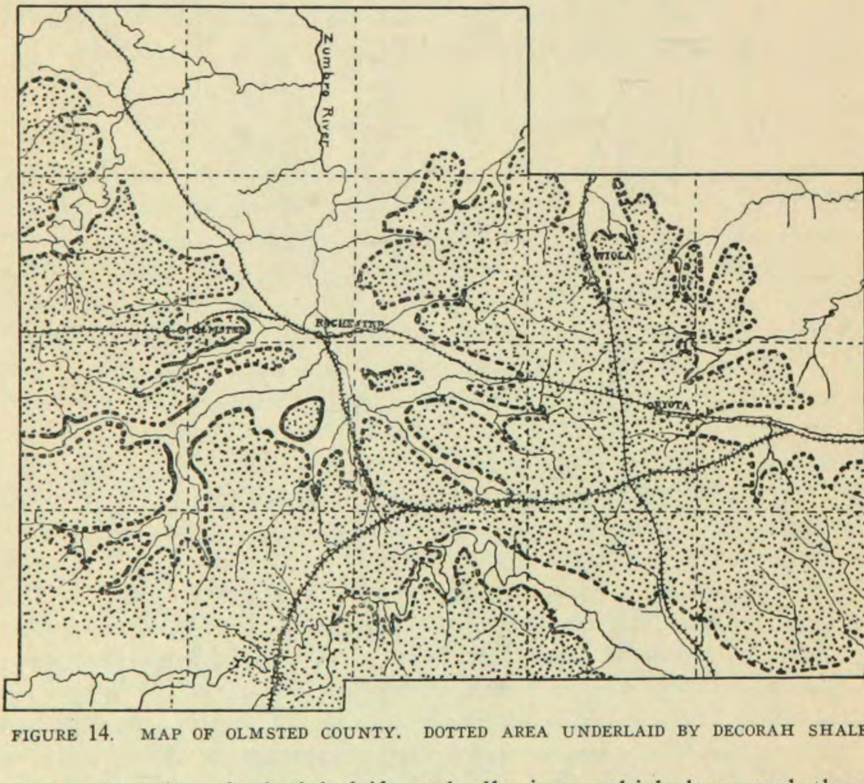


FIGURE 14. MAP OF OLMSTED COUNTY. DOTTED AREA UNDERLAID BY DECORAH SHALE.

ferior deposits of glacial drift and alluvium, which here and there are mixed with loess. The distribution of the Decorah shale in the county is shown in the accompanying map (Fig. 14). The elevation of the shale above sea level is from 1,125 to 1,200 feet. The most favorable localities for the development of this formation for the manufacture of ceramic products are in the vicinity of Rochester and Byron. In the southern part of the county, along the north branch of Root River, the shale outcrops on both sides of the stream, but is of small thickness and is inaccessible at present. Where the overlying limestones are missing, and where the shale is covered by glacial drift only, its presence is not easily detected, but if the neighboring outcrops give no sign of the removal of the shale, it is supposed to be present under the drift. Around the city of Rochester, where a thin layer of the Decorah shale forms a capping on many of the hills, it is covered by only a few feet of drift and soil, and is therefore readily accessible.

Two and one half miles north of the town of Byron on the Patterson farm, the Decorah shale is about 50 feet thick and covers many acres. (See Fig. 4.) Tests on a sample indicate the quality of the shale in other parts of the county. Its plasticity is very high. It requires 35 per cent of water for molding, and has a shrinkage of 11 per cent on drying. In burning there is the usual tendency to form a black core and destroy the brick if the heating is too rapid, but a temperature of cone 02 (2030° F.) can be reached in a slow furnace without the loss of the product. The range of vitrification is as great as in samples of this shale from other places.

At Rochester there is a considerable deposit of alluvium along the Zumbro River. This is known over 40 acres to a depth of 5 feet or more and it is supposed that its content of clay is derived at least in part from the neighboring Decorah shale. It occurs in patches, alternating with sandy and gravelly material, as in most alluvial deposits. The clay slakes in 1 minute, is highly plastic, requires 32 per cent of water for molding, and shrinks 6 per cent on drying. Burning tests are as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
06	Salmon	......	......
05	Red	2	13
1	Red	5	9
3	Red	6	8
5	Red	......	

The clay becomes hard at cone 05 (1922° F.) and has not reached viscosity at cone 5 (2246° F.). It has thus a range of vitrification of considerably over 300°, and should be capable of burning to thorough vitrification without loss. This clay is recommended for further investigation.

A mile south of Byron, at a bridge on the county road, there is an exposure of about 5 or 6 feet of Galena consisting of shale interbedded with limestone. This is not of as good quality as the sample from Fillmore County. It contains a larger proportion of lime and requires a higher temperature for thorough burning. Its plasticity is not as high and the abundance of lime has a very strong tendency to destroy the brick even after burning to as high a temperature as cone 4 (2210° F.).

For 25 years a plant has been at work near the station of Byron on an extensive deposit of sandy yellow loess, 4 feet thick. Over a million bricks per year were produced, but the plant was burned in 1910, and has apparently been abandoned.

OTTERTAIL COUNTY

Types of clay, Pleistocene .... b) Gray lake clay
a) Gray drift

In the town of Fergus Falls a deposit of laminated clay was used 20 years ago for a rather soft and poor grade of yellow brick. The poor qualities of the brick were possibly due in part to the method of burning, but were probably due also to the sandy nature of the clay. The clay is covered by a thin layer of soil and contains no pebbles. Its quality seems to be satisfactory as to plasticity and range of vitrification. It reaches viscosity at cone 6. If market conditions are favorable, it may be worthy of further investigation. The hills south of Fergus Falls may contain similar clay.

Two miles north of the railroad station at Perham is a deposit of laminated clay covering at least 20 acres and 15 feet in thickness. Yellow and blue-gray clays alternate in this deposit, the yellowish color due to oxidation having apparently followed the beds which allowed more rapid circulation. A very few limestone pebbles and a great many cylindrical ferruginous concretions occur in the clay. The clay is capped by soil only. The working qualities of the clay are fair, though it is likely to crack in drying. It burns hard at cone 02. The Northwest Brick Company has been producing common yellow brick from it for nearly 40 years. Conditions are excellent except in the matter of railroad facilities.

At Deer Creek, the Deer Creek Brick Company has opened a pit 4 miles northwest of town, in which are exposed 15 feet of yellow clay and 15 feet of blue-gray clay, all laminated in horizontal layers. It underlies from 3 to 6 feet of bowldery drift. Its working qualities appear to be excellent and it burns hard and buff-colored at cone 2, with a good range of vitrification. The company, which was organized about five years ago, has been producing brick at the rate of about 10,000 per day, working on half-day shifts. The plant is not now active on account of the difficulty of reaching a market from its rather inaccessible location.

Laminated clays are known at two points near the town of Battle Lake. Here, Mr. A. C. Hatch established a brick yard, using a clay which he had found across the lake. The clay was mined by blasting when frozen, and hauled across the lake on the ice. A moderate success was made of a small plant, but the clay is nearly exhausted. Two miles southeast of Battle Lake on the banks of Clitherall Lake are many acres of a similar clay. It is at least 12 feet thick.

At Pelican Rapids, the following series of outcrops is observed in Sec. 22, T. 136 N., R. 43 W.

Gray drift	1 to 15 feet
Yellow laminated clay	12 to 14 feet
Blue laminated clay	4 to 6 feet
White sand	Bottom

The yellow clay was worked until 9 or 10 years ago, but the amount of overburden increased so as to render operations unprofitable. The working and burning qualities of the clay are fairly good. It makes a buff brick without any very great range of vitrification, and before burning it has only a medium tensile strength.

One mile north of Pelican Rapids is a very extensive clay bank of the gray drift which is known to be over 10 feet thick. This can hardly compete with the laminated clays near by.

PENNINGTON COUNTY

At Thief River Falls, which is in the region once covered by Lake Agassiz, a considerable deposit of clay 4 or 5 feet thick was used for brick many years ago. The best clay is now nearly exhausted. Excellent brick were made, and, if other alluvial clays are found, they may be suitable for development.

PINE COUNTY

Types of clay,	2. Recent	Swamp clays
	1. Pleistocene	Red drift and laminated clay

The red drift of most of the county is from the Lake Superior invasion, but older red drift lies below it and the gray drift extends across the southern border. If railroads should be built along the St. Croix River above Kettle Rapids, it may be possible to develop red laminated clay at many places. Analyses are given in Table V, page 53.

Along the railroad, just south of Pine City, a plant was in operation for 30 years, using a deposit which was evidently out-wash of the glacier.

East of the Great Northern Railroad, most of the land is swampy and many of the swamps contain promising clay.

PIPESTONE COUNTY

A large territory east of the town of Pipestone is known to be covered with gray drift at least 10 feet thick. As compared with that at Hutchinson, which is successfully used, this drift contains 22 per cent of sand instead of 30 per cent, but as the clay vitrifies with about the same range and temperature, the slight deficiency in sand can hardly be considered a serious one. The shipping facilities at Pipestone are so good, owing to its four railroads, that this is a very favorable place for the development of the brick and tile industry. Competition is almost entirely from the south, partly from Sioux City and partly from Luverne in Rock County, but, since it seems certain that products can be made of the excellent quality now produced at Hutchinson, this location is worthy of careful consideration.

POLK COUNTY

Types of clay,	3. Recent	....	Lake clays
	2. Pleistocene	....	b) Silts of Red River Valley
			a) Gray drift
	1. Cretaceous (too deep to be of value)		

The silts of the Red River Valley are worked at Fertile, East Grand Forks, and Crookston. These may not all be of the same type, as several varieties of clays accumulated in the Lake Agassiz basin.

At Fertile, the deposit resembles a river delta, occupies about 40 acres to a depth of 40 feet, and is distinctly bedded, with the beds dipping toward the present river channel. The clay is yellow and calcareous, and has very little overburden. Sandy layers are frequently included. In working and burning, it seems to have excellent properties. The plant is producing cream-colored brick by the stiff-mud process. It has a capacity of about 3 million brick per season. Hollow blocks and drain tile are also made.

Two companies are operating upon laminated clays at Crookston. The Bankind Carlson Brick Company has a deposit within the city limits which can be traced all along the river and is known to a depth of at least 12 feet. It is covered only with soil and underlaid with a brown and blue clay of unknown thickness. There are a few limestone pebbles and limey and iron concretions. The lamination in the upper part is paper thin, but in the lower part of the bank there are layers 3 or 4 inches thick. The working qualities of the clay are very good, except that it cannot be dried rapidly without checking. It burns hard at cone 2, and has a fair range of vitrification. The plant is producing common cream brick by a soft-mud process, at the rate of about 4 million in a season. The Crookston Brick and Tile Company operate close to the saw mill on the same deposit. Where exposed in their pit, the clay is a little more sandy. The capacity of the plant is about the same. The City Building Inspector, of Minneapolis, in testing a set of 6 brick from this deposit at Crookston, found a crushing strength ranging from 1,950 to 3,350 pounds per square inch, with an average of 2,500 pounds. The blue clay of the lower levels gives the usual trouble in drying.

At East Grand Forks the silts of the Red River extend for miles up and down the valley and locally are 100 feet thick. They have been leached and weathered yellow to a depth of 5 feet, and for many years this portion has been used for making cream-colored brick. On the east side of the river, work has been in progress over 20 years, and at Grand Forks, on the Dakota side, for a longer time. The same company controls the yards in both Dakota and Minnesota. Steam shovels and better machinery have been installed on the Dakota side, and, if the demand is not great, the plant on the Minnesota side is closed, rather than the other. According to the officers of the company the clay at the two plants is essentially the same. The clay slakes at once and its plasticity is very low. It requires 26 per cent of water for molding, and shrinks less than 4 per cent on drying. Its tensile strength was well above 100 pounds per square inch. Burning tests gave the following:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
03	Buff	0	36
1	Buff	2	30
4	Buff	3	28
6	Buff	......	......

The clay becomes hard at cone 01 (2066° F.), and reaches viscosity at cone 5 (2246° F.). It is capable of being burned to an excellent hard brick.

The North Dakota Geological Survey give the following results on the material from Grand Forks:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
010	Orange	0.5	31
05	Pink	1.0	33
03	Cream	0.1	22
01	Cream to green	2.0	18

"The bricklets, except the one burned to cone 01, were not very strong. The clay was incipiently fused at cone 1, became rapidly vitrified at cone 3, and viscous at cone 4."

Two analyses of clay from near Grand Forks are available, the first of which is furnished by the company and the second quoted from the North Dakota Survey.[1]

Analysis of Silts of Red River Valley

Silica	48.30	51.27
Alumina	8.16	9.33
Iron oxides	2.84	3.52
Magnesia	4.93	2.31
Lime	16.34	11.15
Soda	p. n. d.	2.08
Potash	p. n. d.	0.50
Ignition	18.00	

The underlying gray clay on the Minnesota side was more plastic and showed a greater shrinkage than the yellow clay which was being worked. The preheating process referred to in the chapter on physical properties (page 9) would improve the working qualities of this gray clay. A burning test resulted in a brown brick instead of a buff one, and the temperature of fusion was a few degrees lower. The plant on the Minnesota side of the river has a capacity of about 50,000 bricks per day.

In the neighborhood of Lengby are several lakes in which clay deposits overlie common gray drift. There is hardly enough of the lake clay to be used alone, and the gray drift is, as usual, full of pebbles. The lakes could probably be drained off, and clay deposits reported to be of considerable thickness would be exposed. The good quality of the material for common brick is shown by some brick which were burned eight years ago for the village school.

POPE COUNTY

At Glenwood a small plant was at work many years ago upon a superficial leached deposit of gray drift from which most of the lime-

[1]Clapp, C. H., and Babcock, E. J., Fourth Biennial Report State Geol. Survey of North Dakota, p. 185.

stone apparently had been removed. As the town has grown, this particular deposit has been leveled off and subdivided into city lots, and no similar deposit has been developed in the neighborhood. Although its working properties were fair as regards plasticity, shrinkage, and strength, it does not burn hard until within a few degrees of the temperature of fusion. It is, therefore, not promising for hard-burned brick. The usual quality of gray drift is available, however, along all the hills in the neighborhood and, if it should be developed near the junction of the railroads, a plant using the Hutchinson process might be successful.

RAMSEY COUNTY

Types of clay, 2. Pleistocene ....c) Red lake and river clay
b) Gray lake and river clay
a) Red and gray drift
1. Decorah shale

The Decorah shale, which is so extensively used at West St. Paul in Dakota County, occurs also in Ramsey County, but property is too valuable for excavation at these localities.

The general section of the drift in Ramsey County is as follows:[1]

3. Loam		....	3-10 feet
2. Gray drift	(d)	sand, gravel, and stone....	0-10 feet
	(c)	laminated brick clay	0-16 feet
	(b)	sand, gravel, and stone.....	20 feet
	(a)	till (seen)	0- 2 feet
1. Red drift	(b)	laminated brick clay	0-10 feet
	(a)	till	10-20 feet

Leached gray drift has been used in the northern part of the city of St. Paul for red brick.

The red laminated clay is somewhat sandy, like that at Stillwater. It was once used on Dayton's Bluff. Just south of Como Park a thickness of 10 feet of red laminated clays is visible at the crossing of Lexington Avenue under the Northern Pacific Railroad. From 5 to 20 feet of gray drift lies above it. A sample was taken here as an indication of the quality of these clays in the neighborhood of the Twin Cities, where the gray laminated clays also are used. Tests by the U. S. Bureau of Standards are as follows: The clay contains too much fine sand to work well in an auger machine. The water

[1]Winchell, N. H., Final Rep., Minnesota Geol. and Nat. Hist. Survey, Vol. 2, p. 371.

needed for molding is 20 per cent and the shrinkage on drying is 4 per cent. It burns red and is so sandy that it retains a high porosity, over 35 per cent, up to the point of vitrification. It reaches viscosity at about cone 2 (2138° F.). Between Sibley and Wacouta Streets, red laminated clays were formerly exposed in quantities. In all these places the value of city property is undoubtedly so great that ceramic industries will not make use of the clay, but the results indicate the qualities of the laminated clays near by.

A large part of the county is covered with common pebbly red drift, though gray drift overlies the red in many places. In St. Anthony Park, near the city limits, between Minneapolis and St. Paul, the red drift seems to be coarsely and irregularly stratified, and is made up of a pebbly clay which in its average character is very similar to that at Coon Creek, and elsewhere.

RED LAKE COUNTY

Half a mile from the station of Red Lake Falls is a deposit of gray drift which has been modified by the waters of Lake Agassiz. This was used many years ago, but the enterprise has been abandoned, probably because of the difficulty caused by included pebbles. If either the Hutchinson or Jackson cleansing process could be applied, a plant might succeed, for the town is served by both the Great Northern and the Northern Pacific Railroads, and is in a part of the State that is being rapidly settled.

REDWOOD COUNTY

Types of clay,	4. Recent	Alluvium
	3. Pleistocene	Gray drift
	2. Cretaceous	b) Shale
		a) Basal white clay
	1. Archean	Residual clay

The gray drift at most places in the county is not as good for brick making as the alluvium of the Minnesota River which is successfully used near Morton for brick and tile. Thin layers of Cretaceous shale have not proved to be of value, but the underlying concretionary white clays and the associated Archean residual clay warrant careful prospecting.

A sample of Archean residual clay was taken from the gorge below Redwood Falls where the banks of the river form a bluff. Here the lower 50 feet consist of weathered granite. This underlies a basal

Cretaceous clay described below. The outcrops extend for nearly a mile along the river. The clay is well situated with respect to railroads, but, on account of its scenic features, the property at the exact point of outcrop is reserved as a State Park. As tested in the laboratory, the clay slakes in 1 minute. In plasticity it is low, requiring 33 per cent of water. The tensile strength is about 50 pounds per square inch, but it is not affected by rapid drying. It burned salmon color and hard at cone 1 (2100° F.). It became brown at cone 13, but was still undeformed. The tests indicate that it is a good grade of refractory clay. At one point in this gorge where the original rock was doubtless highly ferruginous the red stain of iron oxide is so great that a "Red Paint Mine" was opened, and a few tons of paint rock were shipped.

Between Redwood Falls and Morton, along the south bank of the Minnesota River, a test pit has been dug by the Morton Brick and Tile Company into a bank of residual decomposed gneiss. This has retained its granitoid texture, and the ferromagnesian minerals have changed to chlorite as the feldspar changed to clay. The resulting clay has a very mottled appearance. It burns to a gray color, becomes hard at cone 2 (2138° F.), and is thoroughly vitrified at cone 13 (2534° F.).

A sample of basal Cretaceous clay was taken near the town of Morton. South of the river on the road to Redwood Falls, where the road has been graded, there is an exposure in the river bluff which is one of the most instructive outcrops of Cretaceous in the State. The section is as follows:

Glacial drift	0 to 20 feet
Black shale	1 foot
Concretionary white shale	3 feet
Smooth white clay	3 feet
Concretionary clay with much coarse grit	5 feet
Conglomerate, quartz pebbles in a concretionary clay	2 feet
Decayed Archean granite and residual clay	5 to 8 feet

This is one of the thickest exposures of the basal Cretaceous known in this region, and shows a definite conglomerate at the contact with the Archean. (See Plate III, A.) Only a foot of Cretaceous shale is visible, but it is clear that the white clay grades into the shale without unconformity. Both the concretionary or pebbly clay and the white clay burn white and are undeformed at cone 33 (3254° F.), and are therefore highly refractory fire clays. Even gritty varieties are refractory. Analyses are given in Table I, Chapter V.

The Morton Brick and Tile Company have made various attempts to use the clay from this deposit in connection with their main deposit which is alluvial clay of the Minnesota River. Mixtures of this refractory material with the alluvial clay have not been found to improve the latter when only a small percentage of the fire clay was used. The deposit here is not large enough to justify attempts to produce vitrified ware by the use of a high percentage of the fire clay. It is not unlikely, however, that larger deposits might be found. The outcrop down the river in Renville County is said to be even thicker, and a similar stratum may be traced up and down the Redwood gorge wherever the Archean clays form the main bank of the bluff. These scattered exposures may represent parts of a single large body of high grade clay under the drift. Relatively small amounts of the fire clay have been worked up without the addition of other clays into fire brick which had the same defects as those made at New Ulm, namely, lack of strength after repeated heating and cooling. The refractoriness is, however, all that could be desired.

As tested by the U. S. Bureau of Standards, these clays have the following properties: Plasticity is low even after grinding and using 29 per cent of water. Drying shrinkage is 4 per cent. The burned color is not quite as clear a white as that of commercial kaolin. The softening point is above cone 32 (3220° F.). There is a rather serious tendency to check in burning, even in hand-molded bricks. The clay needs a plastic fire clay bond in small amounts. Analyses by the Bureau of Standards are as follows:

Analyses of Basal Cretaceous Clays

	1.	2.
Silica	45.14	44.12
Alumina	37.94	38.39
Iron oxides	1.01	1.06
Titanium oxide	1.09	1.17
Lime	0.46	0.28
Magnesia	0.08	0.11
Soda	0.36	0.30
Potash	0.09	0.17
Ignition	14.10	14.70

1. The smooth white clay.
2. The pebbly or concretionary clay.

By washing, the color of this clay after burning might be made as good as that of commercial kaolins.

In Redwood County, near the town of Morton in Renville County, the alluvium of the Minnesota River occupies a great many acres of the river flat. Locally it is 10 feet thick. Under the sod there are

5 feet of black sandy clay, then 5 feet of yellow sandy clay, below which is river gravel. The clay slakes at once, is highly plastic, and requires 27 per cent of water for molding. Its tensile strength is nearly 100 pounds per square inch, though it may be somewhat less if the clay is dried too rapidly. The air shrinkage is 7 per cent. Burning tests are as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Salmon	0	22
02	Salmon	1	22
1	Brown	5	12
2	Brown	6	9

The clay becomes too hard to be scratched with a knife at cone 05 (1922° F.), and reaches viscosity a little above cone 2 (2138° F.).

The Morton Brick and Tile Company have been manufacturing red brick and drain tile for many years in a modern plant of medium capacity. Small additions of the refractory Cretaceous clays do not improve the product.

RENVILLE COUNTY

Types of clay, 4. Recent ....Lake clays
3. Pleistocene ....Gray drift
2. Cretaceous clays
1. Archean residual clay

Lake clays of unknown quality are reported at Boon Lake in the northeast corner of the county. The gray drift of most of the county is of the common type. From Beaver Falls east, along the Minnesota River, Archean residual clay and basal Cretaceous clays are important.

On Birch Cooley, three-fourths miles up the creek from the river bluffs, the "concretionary marl" reported by N. H. Winchell[1] reaches a great thickness. Well records show it at many other places below 100 to 300 feet of drift. This drift overburden is the chief drawback to its extensive development.

At a point two miles below the Lower Sioux Agency, Sec. 10, T. 112, R. 34 (in Birch Cooley), on the north side of the Minnesota, a small creek joins the river. Up this creek, about three-quarters of a mile from the river bluffs, the Cretaceous appears in its banks. A concretionary marl, or apparently limey earth, of a white color, crumbles out under the projecting turf. It appears in fragments of an inch or two, or sometimes larger, with angular outline. The surfaces of these pieces show a great number of round or oval spots or rings, which seem to be formed by the sections of concretions enclosed in the mass. It is rather hard when dry, and nearly white. It is associated with a blue clay, the relations of which cannot here be made out.

At a point a little further up this creek appears a heavy deposit of concretionary,

[1]Winchell, N. H., Final Rep., Minnesota Geol. and Nat. Hist. Survey, Vol. 2, p. 197.

rusty marl * * * in heavy beds that fall off in large fragments like rock. The first impression is that the bluff is composed of ferruginous conglomerate, but there is not a foreign pebble in it. Every little round mass has a thin shell which is easily broken, revealing either a cavity, or a loose, dry earth. These concretions are generally not more than ¼ or ½ inch in diameter; seen 18 feet. Under this is the light concretionary clay or marl already described.

This evidently refers to the basal Cretaceous clay and it is the greatest thickness reported in the State.

Just across the river from the test pit in Redwood County, mentioned above, several ravines have cut through the drift and into a decomposed granite, exposing a yellowish mass somewhat distinct from the green mottled clay of Redwood County. In burning, essentially the same qualities develop. Samples of these clays have been used as refractory material at the plant of the Morton Brick and Tile Company.

A bed of grayish white clay is known 3 miles west from Fort Creek. In an excavation on the upper side of the river road in Sec. 34 the clay is 7 feet thick. The stratification is horizontal and the clay may be closely related to the white concretionary or conglomeritic clays above described.

RICE COUNTY

Types of clay, 2. Pleistocene ....b) Aftonian soil (no value)
a) Gray drift
1. Decorah shale

At Faribault common red brick are made from gray drift where it is locally leached. In former years brick yards used to be operated on gray drift at Northfield, Morristown, and several other localities. The Decorah shale outcrops on both banks of Straight River for many miles, and on the east side of Cannon River, from Faribault northward almost to Dundas. It also fringes the hills in Cannon City, Wheeling, Northfield, and Bridgewater townships. A very promising outcrop occurs one and one-half miles south of the town of Faribault, one-fourth mile above the Rock Island Railroad bridge over Straight River. At this point 10 feet of shale lie just above the limestone. Above the shale is a thin bed of limestone, and several feet more shale below the drift. The shale as sampled is considerably weathered. The tensile strength of these clays is considerably greater than that of the same formation farther north. The water required for molding is 31 per cent. The air shrinkage is 7 per cent. A burning test conducted by the Minnesota School of Mines Experiment Station resulted as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
06	Salmon	......	19
04	Salmon	1	20
01	Cream	......	......
2	Cream	......	......
5	Buff	10	......

The clay becomes too hard to be scratched with a knife at cone 02 (2030° F.), and is not viscous at cone 5 (2246° F.). There is some tendency to form black cores if the heating is too rapid, but with slow heating it can be safely vitrified. The temperature required for vitrification is slightly greater than the Decorah usually requires. The usual difference is found between the upper and lower layers, more limestone being included in the top. A test by the U. S. Bureau of Standards showed a tendency toward forming an efflorescence. This is probably due to the weathered condition of the sample. This location is a promising one for the development of a brick industry.

There are many extensive swamps in the county, and a sample was taken from one which extends over about 60 acres, 6 miles northwest from Faribault. The clay is overlaid with about 2 feet of soil and peat, and seems to be free from impurities except organic matter. The clay slakes in 4 minutes and develops high plasticity with about 30 per cent of water. It shrinks about 8 per cent on drying, and cracks very badly. Many brick fall to pieces. If sand were available in the neighborhood and market conditions were favorable, the clay might be available for common red brick. It is found to have a fairly good range of vitrification, reaching viscosity at cone 3.

ROCK COUNTY

At Luverne a plant has been active for the last 15 years, producing excellent brick and tile from the gray drift which covers a large part of the county and is worked here to a depth of 10 feet. The limey pebbles which occur in the drift here are said to have a less serious effect than elsewhere, and, though some of the product may be injured by their presence, there is only a very small per cent of loss by the crumbling of the brick and tile after burning. The larger pebbles are removed from the clay by the use of conical rolls. The plant has a capacity of about 50,000 brick per day.

In the neighborhood of Beaver Creek, on the south side of the road where the railroad crosses Beaver Creek, a sample was taken of the gray drift which seems to resemble that exposed in the surrounding country. It is somewhat more sandy than the average and contains many pebbles, some of which are limestone.

The sand-lime brick plant at Luverne should be mentioned.

ROSEAU COUNTY

A quarter of a mile from the station at Badger, the gray drift has been worked over somewhat by the waters of Lake Agassiz, and is rich enough in clay to make brick. The clay contains a rather high proportion of limestone pebbles, and owing to these, the product is inferior. A process for removing the limestone would make it more satisfactory.

At the town of Roseau are several acres of similar modified drift at least 10 feet thick. It is highly calcareous, but the limestone is not present as pebbles. In working and burning it shows a very much better quality than that at Badger. A few yellow brick were made from it several years ago.

ST. LOUIS COUNTY

Types of clay,	3. Recent	Swamps and lake beds
	2. Pleistocene	d) Gray laminated clay
		c) Red laminated clay
		b) Red drift
		a) Gray drift
	1. Huronian	Paint rock

Just south of the town of Tower is a swamp that extends over several hundred acres. Borings show 40 feet of clay near the center. Above the clay, which contains very few limey pebbles, are several feet of peat. The North American mine is close to this deposit, and its underground workings may eventually drain the swamp. The clay slakes at once, shows a high plasticity, and requires 39 per cent of water for molding. The air shrinkage is very great, and the clay can hardly be prevented from cracking. The tensile strength is consequently small. As tested by the U. S. Bureau of Standards, it gave the following: The color varies from light red at low temperatures to chocolate at higher temperatures. The porosity ranges from 28 per cent at cone 010 to 16 per cent at cone 06, and drops rapidly to 3 per cent at cone 04. The best burning temperature would be at about cone 04 (1958° F.). The range of vitrification is fairly good.

A plant was started to manufacture the brick and tile from this material, but difficulty was experienced in drying the ware. On account of its good range of vitrification this clay might be valuable for making sewer pipe if it developed enough strength in the burned ware and could be safely dried. It has a lower temperature of fusion than most sewer pipe clays and this is sometimes an indication of weakness. If a less plastic material can be found in the neighborhood and mixed with this clay, its properties might be more satisfactory.

At Buhl, the Grant open pit mine has exposed by stripping, a considerable body of swamp clay overlying gray drift. This material must be moved in mining and, if care was taken to avoid mixing with the drift, it would be available for making common brick. It has much the same quality as that at Tower and could be used for similar purposes. Organic matter is present and it is necessary to burn slowly to avoid the production of black cores.

At the town of Floodwood is the dividing line between the gray laminated clays which occur from here west, and the red laminated clays which occur in the eastern part of the State. About a mile northwest of town on the McCormick farm, a well has been dug which passed 12 feet of yellow clay and 6 feet of gray clay. The deposit can be traced over several acres and may extend much farther. It is covered with only a thin soil. The clay slakes at once, has a rather low plasticity, requiring 24 per cent of water for molding. Its tensile strength is well above 100 pounds per square inch, and it shrinks 2.5 per cent in drying. Burning tests gave the following results:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Buff	1	35
1	Buff	4	30
3	Buff	8	21
6	Buff	......	......

The clay becomes hard at about cone 1 (2100° F.), and reaches viscosity at cone 5 (2246° F.). This test was made on the yellow clay and a similar test on the blue clay showed a slightly greater tendency to shrink and warp.

Gravelly drift, both red and gray, may be found in the immediate neighborhood of Floodwood.

The red laminated clays exposed along the banks of the Savanagh River near its mouth at the southeast edge of town were also found in excavations. The exposure is 10 feet thick and the bottom is not seen. The clay slakes in 2 minutes, shows a fairly high plasticity, and requires 25 per cent of water for molding. A test by the Bureau of Standards shows that it needs lubrication to work in the auger machine. Its tensile strength is nearly 100 pounds per square inch and the air shrinkage, 6 per cent. Burning tests gave the following results:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Salmon	1	20
04	Red	3	15
02	Red	8	6
01	Red	9	4
1	Red	11	......

The clay becomes too hard to be scratched with a knife at cone 05 and reaches viscosity at cone 1. On account of the easy accessibility of several other types of clay, mixtures of this clay were also burned, but none seemed to show a greater range of vitrification, or other improvement in properties. At the lower porosities this clay shows a well-vitrified structure.

On the Mesabi Range, notably at Coleraine and Hibbing, bodies of clay are interbedded with the iron ore. Iron has been concentrated in the clay, but it is not rich enough to be an ore. It is highly colored and commonly known as "paint rock." The beds vary greatly in size and texture. Some of the clay is sandy, but some is smooth and plastic. Where the ore is found both above and below the paint rock, it is necessary to remove the paint rock in order to work the open pits. If a use could be found for this material, it could easily be separated from the rest of the dump, which consists largely of gravel overburden. At Coleraine 20 feet of paint rock is being removed. The paint rock slakes very quickly and is highly plastic, requiring 27 per cent of water. Its tensile strength is a little over 50 pounds per square inch, and its air shrinkage 4.5 per cent. In spite of its high content of iron, it does not burn hard below a temperature of 2200° F., but is viscous at 2500° F.

Above the iron ore is a formation known as the Virginia slate. At the Norman mine at Virginia, over 20 feet are exposed. This also is highly ferruginous, and is not plastic, even when powdered. It has very little tensile strength and does not burn hard at a temperature of 2300° F.

SCOTT COUNTY

Types of clay, 3. Recent .... Alluvium
2. Pleistocene .... b) Gray lake clay
a) Gray drift
1. Cretaceous

Alluvium occurs all along the Minnesota River and in the bluffs at many points gray laminated glacial clays are known. A sample of gray drift from 3 miles south of Shakopee contains many limestone pebbles. At La Huiller Mound, between Jordan and Shakopee, a white clay resembling the Cretaceous was sampled for the state museum by N. H. Winchell.

In Shakopee, river alluvium is known to extend over 20 acres to the unusual depth of 30 feet. A dark-colored clay some distance from the river is found to be more plastic than that closer to the river, and the two are mixed to produce the proper clay for soft-mud red bricks. Some repressed brick are made at this plant. The clay slakes in 3 minutes, and its plasticity is rather low. It requires 23 per cent of water for molding and shrinks 4 per cent on drying. Its tensile strength is about 100 pounds per square inch, and is not much less if the clay is rapidly dried. Burning tests resulted as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
02	Salmon	0	13
2	Brown	3	15
3	Brown	5	22
5	Brown	......	......

The clay becomes hard at cone 01 (2066° F.), and reaches viscosity at cone 4 (2210° F.). The plant has a capacity of about 3 million brick per season.

At Blakeley a deposit has been used in the manufacture of cream-colored brick. It consists of laminated clay about 30 feet thick, the upper half of which shows the common weathered yellow color, characteristic of these clays. The extent of the deposit is uncertain on account of the talus from the overlying hill of drift, but it can be traced for some distance along the Minnesota River bluff. There is the usual difference between the upper and lower clays. Neither shows a tensile strength as high as 100 pounds per square inch, and, while the upper clay shows an air shrinkage of 1.5 per cent, the lower shows over 5 per cent. A mixed sample such as is used at the plant shows the following characters:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
1	Buff	1	30
3	Buff	5	20
4	Buff	......	2

Clay becomes hard at about cone 1 (2100°F.), and is near viscosity at cone 4 (2210° F.). A plant established here has been operated steadily since about 1890, making common brick. Recently a large proportion of hollow brick have been made with a stiff-mud machine which has a capacity of about 35,000 brick per day.

At Belle Plaine, in this county, a plant is in operation about a mile south of the town. The clay bank shows the following section:

Gravelly drift	30 feet
Yellow silt	10 feet
Gray clay	15 feet
Very dark gray clay	15 feet

The different portions of the bank are not regular in their stratification, but the clay seems to have been thrust up in a sort of arch in this neighborhood and each part of the section grades into the overlying and underlying parts. The yellow silt of the section can be used as sand in tempering the lower clay. The working properties of the clay are excellent, and the plant which is operating can produce about 30,000 soft-mud cream-colored brick per day.

SHERBURNE COUNTY

Types of clay, Pleistocene................c) Gray lake and river clays
b) Red drift
a) Gray drift

An area in the neighborhood of the town of Elk River is covered with red drift, without the overlying mantle of gray drift found in most of the county. The sample taken slakes in 4 minutes. After grinding, it shows a high plasticity and a shrinkage of 8 per cent on drying. The tensile strength is, however, only a little over 50 pounds per square inch. Burning tests are as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Salmon	1	16
04	Salmon	1	15
02	Salmon	3	12
1	Red	6	3

The clay becomes hard at cone 05 (1922° F.), and reaches viscosity at cone 1 (2100° F.). With this red drift available, there is little need of using the gray drift for common brick.

Two miles south of Sauk Rapids, and across the Mississippi River opposite some brick yards in Stearns County, there was at one time a brick yard producing cream-colored brick from yellowish laminated clay of the common type.

SIBLEY COUNTY

Gray drift covers nearly all the county, except along the Minnesota River where alluvium is found. The latter makes fair red brick. At Henderson, if the richer clay is selected from the deposit, 50 per cent of sand from the bed of the river is added for making sand-mold brick. The clay without the additional sand shows a rather high air shrinkage and, though its range of vitrification is about the average, it reaches viscosity at cone 1 (2100° F.). With sand added, this clay would no doubt have the properties of the other alluvial deposits. The plant is capable of producing about 10,000 red brick per day.

STEARNS COUNTY

Types of clay, 4. Recent ....Lake clay
3. Pleistocene ....c) Gray lake and river clays
b) Red drift
a) Gray drift
2. Cretaceous ....b) Shale
a) Basal clay
1. Archean ....Residual clay

The gray drift is abundant in the county but where tried at Collegeville and near St. Cloud, it was not satisfactory.

Just west of Richmond at the west end of a wagon bridge over Sauk River, is an exposure of Cretaceous, which has been explored by shafts and tunnels in search of coal. Gray shales outcrop above water level. A hole about 100 feet deep reached granite, but passed a large mass of basal Cretaceous and, below it, a white gritty clay retaining some traces of granitoid texture. This is probably decayed Archean granite. The section resembles that exposed in Redwood County. The gritty clay is plastic and has an air shrinkage of 4 per cent. At cone 04 (1958° F.) it is buff and too hard to be scratched with a knife. At cone 13 (2534° F.) it is purple, but still undeformed and very porous.

At this Richmond outcrop the bottom of the basal conglomeritic clay is below water level in the river. A boring into the hard clay at water level to test the thickness of the formation, showed at least 6 feet of white clay below, and 7 feet may be seen outcropping above water. It cannot be said with certainty where this Cretaceous formation ceases and the residual Archean comes in below, for they are of similar character.

This basal Cretaceous is overlaid with a dark gray shale and some small lignite layers. A near-by shaft 25 feet deep passed a 6-inch layer of lignite enclosed in blue clay which was proved to reach a depth of 50 feet by boring in the bottom of the shaft. Shale of the same general appearance was observed in a ravine 2 miles north of Richmond. A sample of the clay slakes in 3 minutes, and is fairly plastic, though it has a somewhat waxy feel apparently on account of included mica scales. It requires 16 per cent of water for molding. Burning tests by the Minnesota School of Mines Experiment Station resulted as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
011	Salmon	0	14
07	Salmon	0	13
05	Salmon	......	......
02	Salmon	......	......

The clay becomes too hard to be scratched with a knife before reaching cone 011 (1688° F.), and, if carefully burned, can be heated to cone 02 without deformation. The presence of organic matter, however, is responsible for the production of black cores with great swelling and cracking if the clay is not thoroughly oxidized. The range of vitrification is sufficient to make it perfectly safe to burn this clay to a dense product, but, owing to its low fusion temperature, it is not desirable material as a binder in making refractory ware of the non-plastic kaolins which underlie it.

Three miles south of St. Cloud the laminated clays are developed over many acres of land, along the west bank of the Mississippi. They have a thickness of over 30 feet, but over much of the surrounding territory they are deeply buried under deposits of sand. Here, a tributary stream, Three Mile Creek, has eroded the sand, and made the clay accessible. Two brick yards are at work upon the material. As usual the clay has irregular pockets and layers of sand, which, when rather fine, are called quicksand. These sands make very poor brick, but if proper attention is paid to the mixing of the plastic and sandy parts of the deposit, excellent cream-colored brick can be produced. The clay burns hard at cone 03, and has a range of vitrification much like that of other laminated clay. Both solid brick and hollow tile and building block are produced at each place, and each plant has a capacity of over 20,000 brick per day. At one plant round down-draft kilns are being installed so that the temperature of the burning of the tile can be more accurately controlled. A little farther south a similar deposit has been worked at St. Augusta. Work was started here in 1890, but was abandoned in 1910.

At Collegeville, for the buildings of St. John's College, brick were made from a small deposit of yellowish laminated clay which seems to be entirely surrounded by coarse gravelly drift. It may be only a fragment of some larger deposit which was caught up by a later ice invasion and deposited in the midst of a gravelly moraine. It shows the usual range of vitrification, reaching the point of fusion at cone 3 (2174° F.). The deposit is small and relatively inaccessible.

Brick have been made at Albany from clay obtained in the banks of a stream at the southwest side of town. It is said that the clay near water level is quite free from lime pebbles and burns red. At the top of the bank, the gray drift is full of limestone fragments and is unsuitable for brick manufacture without some cleansing process.

At Miers Grove, in this county, over several acres north of town the gray drift has been leached of some of its lime contents. The thorough leaching extends to a depth of only 3 or 4 feet and apparently the original deposit contained a great many other pebbles besides those of limestone. The clay slakes in 3 minutes and is fairly plastic, requiring 29 per cent of water for molding. Its pebbly character keeps its strength somewhat below 100 pounds per square inch. Its air shrinkage, however, is nearly 7 per cent. The plant which has been working this clay for a local brick supply has a capacity of 20,000 brick per day, but the product is a very weak red brick.

Near Paynesville, a brick plant has been started to make use of a delta deposit on the shore of Eden Lake, near the mouth of the incoming creek. This was used to a depth of 16 feet without finding bottom, and is known to extend over 8 acres with a much larger area under the water of the lake. Water had to be pumped from the pit which extended below the level of the lake, but the seepage through the clay was relatively slow. The clay slaked at once, was highly plastic and required 21 per cent of water for molding. It shrinks 3 per cent on drying and has a tensile strength of about 150 pounds per square inch, even when rapidly dried. It burns to an excellent quality of red brick. The plant made stiff-mud brick with a capacity of 30,000 per day.

STEELE COUNTY

Deep well sections show the presence of Decorah and overlying shales at several localities beneath the drift, notably at Owatonna. Fire clay was reported a mile east of Owatonna.[1] It is not now used.

Half a mile west of the station of Meriden on the Northwestern Railroad, is a deposit of clay several feet thick. It extends over at least 60 acres, and resembles the loess, but, since it lies in a swamp, it is not all exposed and it may contain some glacial and recent sediments in addition to the loess. The clay slakes at once and shows a rather low plasticity. It requires 27 per cent of water for molding, and its air shrinkage is less than 4 per cent. Burning tests yield a light brown brick, without much shrinkage, and with an absorption of 30 per cent. Its range of vitrification, however, is only about 40° F., so that it can not safely be burned to a hard product. An analysis by Dr. E. P. Harding, of the University of Minnesota, is as follows:

Analysis of Loess Clay

Silica	60.00
Alumina	11.45
Iron oxides	3.90

[1]Harrington, M. W., Final Rep. Minnesota Geol. and Nat. Hist. Survey, Vol. 1, p. 402.

Magnesia	4.05
Lime	6.48
Potash	4.09
Soda	2.84
Moisture	2.32

The clay does not seem to be as promising as some of the other deposits of loess.

STEVENS COUNTY

Stevens County has a cover of gray drift which, where modified by water action, as at Morris, makes fairly good brick. At other points brick could be made from the drift only after the removal of limestone, but recent lakes may contain some good clay.

SWIFT COUNTY

Types of clay, 3. Recent .... Alluvium
2. Pleistocene .... Gray drift
1. Archean residual clay

Gray drift and its outwash are the chief deposits in the county and neither is very promising except for common brick. Alluvium is of small importance. Decomposed granite was found in a well at Benson at a depth of 400 feet, and drilled into for 300 feet. At Appleton and elsewhere decomposed granite is closer to the surface. At Benson some sandy surface clays in the nature of outwash or loess and surface wash were used for red brick, but were found too full of limestone for good products.

TODD COUNTY

Types of clay, 2. Recent .... Lake clays
1. Pleistocene ....c) Gray lake clays
b) Red drift
a) Gray drift

Most of the county is covered with gray drift and many attempts to use it have failed on account of the lime pebbles it contains.

The most important of the laminated clays is a deposit on Sauk Lake, most easily reached from Sauk Center, in Stearns County, three or four miles to the south. The clay bank rises steeply from the shore of Sauk Lake to a height of 15 or 20 feet, and extends under the level surface several rods back from the top of this bank. The clay directly underlies the soil, although in some places the upper beds are somewhat sandy. Pits have been opened at numerous points along the shore, and the section exposed varies considerably in different parts of the bank. Limey concretions occur in a few spots. It is reported that the best clay occurs at water level. This is gray in color, while the main part of the bank above water level is yellowish white. Warren Upham concluded[1] that this clay accumulated in a channel in the melting ice sheets while a large mass of ice still occupied the basin of Sauk Lake. From the different clays in the bank a variety of products have been made, including both red and cream brick, hollow brick, terra cotta, and flower pots. Samples were taken of both the yellow and gray clays. The gray clay shows greater shrinkage and tendency to crack than the yellow clay. While the average air shrinkage is 3.5 per cent, the blue clay showed 5.5 per cent. The average of the bank gave the following results:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Salmon	0.5	21
02	Salmon	1.0	22
2	Buff	5.0	14
3	Buff	......	......

The clay burns hard at cone 02 (2030° F.), and becomes viscous at cone 3 (2184° F.).

Mr. David Pangburn, who has taken the lead in the development of the deposits and in experimental work to show the availability of the clay, has now retired, and active work upon the deposit has been dropped. Plans are in progress for reorganizing the industry, and it is thought that with the large amount of good clay available excellent products will be turned out, and shipping facilities will be provided.

At Clarissa Spur, near the station of Clarissa, in this county, a plant is making use of a sandy laminated clay. The clay is known to be 12 feet thick with an overburden of only 2 or 3 feet, and extends over several acres. The clay slakes in 4 minutes, and has a rather low plasticity, and an air shrinkage of less than 3 per cent. The tensile strength is nearly 150 pounds per square inch. The range of vitrification is from cone 1 (2100° F.) to cone 5 (2246° F.), or more. Brick are made by the soft-mud process and the plant has a capacity of 10,000 brick per day.

From one to two miles east of Staples along the Northern Pacific Railroad, are several acres of laminated clay, known to extend

[1]Upham, Warren, Final Rep., Minnesota Geol. and Nat. Hist. Survey, Vol. 2, p. 578.

to a depth of 6 feet. These have been worked at two brick plants for common red brick and are said to contain too many limestone concretions if worked to a greater depth. The plants have a combined capacity of about 40,000 brick per day, but they are not now in operation. The clay slakes in 2 minutes, is highly plastic, requiring 28 per cent of water for molding. The tensile strength is over 100 pounds per square inch, but there is danger of cracking if rapidly dried. The air shrinkage is nearly 6 per cent. Burning tests are as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Salmon	1	25
03	Salmon	2	23
01	Salmon	2	23
1	Green	......	......

The clay becomes hard at cone 03 (1994° F.), and is viscous at cone 1 (2100° F.).

At Birch Lake, in this county, the railroad passes the north shore of the lake about a mile east of town, and many years ago a brick plant made use of some laminated clay found along the shore. It may be in part a relatively recent formation, but is probably also partly of glacial age. The character of the clay is very similar to that at Sauk Lake, just described, but its extent is not well known.

Just southwest of Burtrum, two brick plants have been built to use clays which consist of outwash from the drift. The beds are sandy and irregular, but can be traced over many acres, and are exposed in some places to a depth of 16 feet. The clay slakes at once, and its plasticity is low. It requires 21 per cent of water for molding, and shrinks about 5 per cent on drying. Its tensile strength is nearly 200 pounds per square inch, though somewhat less if rapidly dried. The clay burns salmon-colored at low temperatures, but buff or green at higher temperatures, indicating the presence of considerable lime. This lime is probably derived from wash from the gray drift, which extends nearly up to this point. The clay burns hard at cone 01 (2066° F.), and reaches viscosity at cone 4 (2210° F.). Neither of the plants is now in operation, although the material seems to be fairly good.

In the midst of the gray drift in the morainic belts, there are a great many pot holes where the wash from the gray drift has accumulated in swampy places. Two miles west of Long Prairie a brick yard has made use of some small deposits of this sort for a common red brick. The deposits are nearly worked out and it is not likely that others will be started as no others are so easily accessible. A similar deposit occurs about half a mile east of Eagle Bend, and several years ago was used for a kiln of brick. It is small and contains many limestone pebbles.

TRAVERSE COUNTY

Types of clay, 2. Pleistocene .... Gray drift
1. Cretaceous

Gray drift somewhat modified by Lake Agassiz is the chief available clay.

There is an indication that a very large part of the county is underlaid by Cretaceous clay. Most of it, however, is covered with glacial drift and is not readily accessible. Across the river, in South Dakota, is an exposure that was brought to our attention by Mr. A. Parker, of Brown Valley. The clay is at least 40 feet thick and probably much more, and extends for miles along the valley. It is a stratified clay with blue and yellow layers and where it was sampled the glacial drift above it is about 20 feet thick. It is in a situation favorable for excavation, but is a mile from any railroad. The clay slakes in 4 minutes, and is highly plastic, requiring 34 per cent of water for molding. It has a tensile strength of over 100 pounds per square inch even if rapidly dried. It has the further desirable quality of developing considerable strength after being slightly compressed even if it has been separated into several parts as in the auger machine. This is one of the few clays tested which developed this adhesive character. Its air shrinkage is 11 per cent. Burning tests are as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
06	Salmon	4	9
02	Red	7	3
2	Red	......	......
3	Red	......	......

The clay becomes too hard to be scratched with a knife somewhat below a temperature of cone 010 (1742° F.), and is still undeformed at cone 3 (2174° F.). The range of vitrification is about 400°. If rapidly heated, there is organic matter enough present to cause swelling and the formation of a black core, but, if thoroughly oxidized, this can be easily avoided. The analysis of the clay is given in Table II.

WABASHA COUNTY

Types of clay, 3. Recent .... Alluvium
2. Pleistocene .... b) Loess
a) Gray drift
1. Cretaceous

At the town of Wabasha a plant was in operation for about 20 years on a deposit of loess loam on a terrace of the Mississippi River. It has a thickness of 4 or 5 feet for at least 40 acres. Although the loess is rather sandy, it produced a good red brick. About 500,000 brick were manufactured per year, but work was stopped about 5 years ago on account of poor market conditions.

Half a mile from the station of Elgin, in this county, loess loam to a thickness of 12 feet overlies a deposit of stratified sand, over an area of 25 or 30 acres. A small hand mold brick plant has been in operation for over 30 years, and the capacity of the plant has been about 250,000 bricks per season. A similar deposit occurs near the station at Plainview, and was used for a time.

The alluvial clays along the Mississippi River have not been worked and it is unlikely that they will prove to be of much value. The gray drift covers most of the county, but is inferior to the loess and alluvium.

Cretaceous clays probably exist in Wabasha County, although none have been seen in place. Small pieces of clay similar to the Cretaceous clays of Belle Chester and Clay Bank were observed at numerous places in the glacial drift. It is not improbable that careful prospecting would result in the discovery of local deposits of Cretaceous clay in the northern part of the county, for example at Oak Center.

WADENA COUNTY

Several attempts have been made to use the common gray drift, but the limestone caused the usual difficulty and no one has established the necessary process for removal of the pebbles. The town of Wadena is favorably situated for such an establishment.

WASECA COUNTY

Gray drift was formerly used for common brick at several small yards. Possibly glacial or recent lake clays worth developing will be found. The Decorah shale is buried deeply under the drift.

WASHINGTON COUNTY

Types of clay, 2. Recent ....Lake clay
1. Pleistocene ....b) Red lake clays
a) Red and gray drift

The Forest Lake Brick and Tile Company has a pit south of Forest Lake along the Northern Pacific Railroad. This is situated in gray drift which is a little less gravelly than the usual type. At the plant the clay is ground, but limestone pebbles are not removed. The capacity is about 10,000 red brick per day. The clay slakes very promptly and shows a fairly high plasticity. Its air shrinkage is 4 per cent and its tensile strength is about 125 pounds per square inch. Burning tests are as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
04	Light Red	......	......
02	Red	0.7	14
01	Red	1.0	12
2	Red	......	......

The clay becomes hard at cone 03 (1994° F.), and shows no sign of becoming viscous at cone 2 (2138° F.). Although it might be improved by the removal of the limestone pebbles, it seems to supply a satisfactory product after simple grinding. It must be burned, however, to a fairly high temperature or the lime particles will greatly weaken the product.

The plant was first built here to use red drift that was loaded on cars, hauled a quarter of a mile to a barge which transported it several miles across the lake. The cost of transportation was heavy and it was abandoned for the more accessible gray drift. The sample taken indicates, however, the excellent quality of the red drift of the region. It slakes at once and after the gravel has been crushed to 40-mesh, the plasticity is fairly high. The tensile strength is considerably over 100 pounds per square inch even after rapid drying. The water required for molding is 20 per cent and the air shrinkage 4.5 per cent.

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
07	Red	1	15
05	Red	2	14
1	Red	7	5
3	Red	8	4

The clay becomes hard at cone 06 (1886° F.) and is approaching viscosity at cone 3 (2174° F.).

At a point two or three miles south of the town of Afton, a sample of a clay that seems to be red drift was obtained. This is much less pebbly than the average red drift and shows the usual good range of vitrification. The material is not especially accessible to any of the large markets.

At Stillwater, red laminated deposits occur along Brown's Creek, just above its mouth. These were described by N. H. Winchell[1]

[1]Winchell, N. H., Final Rep., Minnesota Geol. and Nat. Hist. Survey, Vol. 2, p. 394

as tripoli, because they were rather more gritty than most of the laminated deposits discovered. Winchell, however, notes the probability of its having an origin similar to that of the red laminated clays at St. Paul and elsewhere. The clay slakes in 1 minute, is not very plastic, and requires only 20 per cent of water for molding. The tensile strength is a little less than 100 pounds per square inch, but it can be dried rapidly without injury and even after it has been cut in two, if again pressed together in the plastic state as in the auger machine, it shows considerable strength. The air shrinkage is only 2.2 per cent. Burning tests are as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Salmon	1	20
03	Salmon	2	17
01	Red	5	10
1	Red	6	3
3	Red	......	......

The clay becomes hard at cone 02 (2030° F.), and reaches viscosity at cone 2 (2138° F.). Analyses are given in Table IV (page 52). On account of its low temperature of fusion, it was tested as a slip clay and in preliminary tests it proved very satisfactory.

Just south of Stillwater, the shores of Lily Lake consist of lake clays of a quality suitable for hard common red brick. They are known to exist to a depth of 10 feet over several acres. They are not conveniently situated as regards market. There is no railroad near the clay, and there is a steep hill between the lake and the city of Stillwater. The excellent quality of the clay, however, is shown in the following tests. It slakes in 2 minutes, and is very highly plastic, requiring 19 per cent of water for molding. It shrinks a little over 3 per cent on drying and has a tensile strength of nearly 100 pounds per square inch. Burning tests are as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
06	Salmon	1.0	14
02	Red	2.0	12
1	Red	4.0	9
3	Red	5.5	6
5	Red	......	......

The clay burns hard at cone 02 (2030° F.) and is viscous at cone 5 (2246° F.).

WATONWAN COUNTY

Types of clay, 2. Recent ....Lake and swamp clays
1. Pleistocene ....Gray drift

In this county most of the surface material under the soil is typical gray drift, although the kettle holes and swamps contain some clay washed from the hills of gray drift. A sample of the drift, taken from Sec. 13 near St. James, would require the removal of the limestone pebbles for the successful production of brick or tile.

The swamp clays seem to be of excellent quality. Samples were taken from a deposit 2 miles northeast of Madelia, where a brick yard operated some 13 years ago. Sand was mixed with the clay and the product made a light red brick. At Odin a similar deposit was sampled. This has been thoroughly prospected but has not yet been developed. There are several acres of the clay known to be 16 feet thick. Burning tests at the Minnesota School of Mines Experiment Station gave the following results:

Madelia Clay

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Salmon	0	
03	Salmon	1	24
1	Salmon	2	21
3	Brownish gray	3	14
5	Yellowish gray	......	......

Odin Clay

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
06	Red	0	15
03	Red	1	14
01	Red	3	11
2	Red	4	7
3	Red	5	5

Both these clays are highly plastic, dry safely to a strong brick, and show an excellent range of vitrification.

WILKIN COUNTY

Wilkin County has only the common gray drift modified north of Breckenridge by Lake Agassiz and the Red River.

About a mile north of the town of Breckenridge, a brick yard has been operated occasionally since 1880 on clay which outcrops in the east bank of the river. The thickness of the deposit is known to be 30 feet in some places, but as here exposed and weathered, only about 10 feet are available. The clay slakes in 4 minutes, is highly plastic, and requires 23 per cent of water for molding. The air shrinkage is 14 per cent and it has a tendency to crack in drying. It burns hard at an unusually low temperature, below 1700° F., and on being burned to higher temperatures has a further tendency to crack.

WINONA COUNTY

Types of clay, 4. Recent ....Alluvial clays
3. Pleistocene ....b) Loess clays
a) Gray lake clays
2. Decorah shale
1. St. Lawrence formation

There is very little drift in this county. The chief formation valuable for brick and tile is the loess loam. This forms a mantle covering the entire county, except along the bottoms of the stream valleys where it has in some places been washed away and elsewhere modified by stream action. Even in the river valleys, especially near the Mississippi River, the loess forms here and there a thick covering on the terraces and lower slopes of the valley sides. The best deposit observed is at Dresbach, where it has been worked for some 30 years for the manufacture of common red brick. At one time there were four large brick yards here, all using the loess, but no work has been done at this locality since 1906. Other places where the loess forms workable deposits are Winona, Dakota, Homer, Lewiston, Utica, and St. Charles.

The undeveloped deposit at Homer is in Secs. 32 and 33, T. 107 N., R. 6 W., on a terrace along a ravine. It is 4 or 5 feet thick, and is known to extend over 6 acres and probably a great many more. The clay slakes in 1 minute, and shows fairly high plasticity. It requires 24 per cent of water for molding, and shrinks 5 per cent on drying. Burning tests are as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
05	Red	1	20
02	Red	2	17
01	Red	4	14
2	Red	5	13
5	Red	......	......

The clay becomes too hard to be scratched with a knife at cone 02 (2030° F.), and reaches viscosity at about cone 6 (2282° F.). It is not known whether there is enough of this deposit to warrant the erection of a large plant, but its quality appears to be of a grade good enough to make a very excellent hard burned or even vitrified red brick.

Four miles northwest of Winona more than 100 acres of loess loam are exposed to a depth varying from 8 to 20 feet. It is irregularly sandy, and has a few small beds of gravel. A plant is turning out red brick of very fair quality at the rate of about 35,000 per day.

Three miles southwest of Winona is a deposit which shows the following section:

Soil	6	inches
Sandy yellow loess	2	feet
Very plastic red clay	14	inches
Plastic yellow massive clay	3½	feet
Stratified yellow sandy clay	4	feet

A sample taken includes all of the section except the soil. Each clay slakes in a very few minutes and develops a fairly high plasticity. The mixture requires 36 per cent of water for molding, has an air shrinkage of 10 per cent, and shows a strong tendency to crack on drying. When properly burned it forms red bricks which become hard at cone 010 (1742° F.). When rapidly burned, black cores develop and organic matter destroys the brick. If slowly burned it does not become viscous at a temperature of cone 02 (2030° F.). It has thus a range of vitrification of about 300° F. and can be burned safely to a fairly good hard product.

Near the clay just described alluvium has accumulated along Burns Creek. This extends over more than 40 acres and is 12 to 14 feet thick. The clay is blue-black and very plastic, and most of it is free from pebbles. The clay is used for mixing with the clays in the same neighborhood, but the plant is at a disadvantage in being located some distance from the railroad. The alluvial clay slakes in 4 minutes and requires 23 per cent of water for molding. Its air shrinkage is 2.5 per cent. It burns salmon color at low temperatures, but becomes brown when well vitrified. It becomes hard at cone 01 (2066° F.), and is not yet viscous at cone 4 (2210° F.). About three million brick are produced each season at this plant.

The Decorah shale occurs in a small area in the southwestern corner of the county, near the town of St. Charles, where it outcrops 40 feet thick under 30 feet of drift. The shales of the St. Lawrence formation outcrop at Dresbach, but are thin. A sample taken does not slake, and retains a porosity of 20 per cent up to cone 4, when it becomes gray in color and hard.

WRIGHT COUNTY

Types of clay, 2. Recent	b)	Alluvium
	a)	Lake and swamp beds
1. Pleistocene	b)	Gray lake clay
	a)	Gray drift

Gray drift covers most of the county. At Otsego an attempt to use the drift failed on account of the limestone contained. Two or three attempts have been made to use the deposits around Buffalo. Many thousand brick have been made from the upper leached portion of the drift where it is relatively free from limestone.

At Dayton, near the mouth of Crow River, laminated clays, which show the usual characteristics, have accumulated in great quantity. A brick yard owned by Mr. Prosper Vassar has exploited these clays since 1880, and has thus far used only the upper leached portion of the deposit. This has a few limey concretions, but has yielded excellent common brick for local use. The lower blue clay is more plastic, requires more water for molding, and shrinks about three times as much. Burning tests of the yellow clay are as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
04	Buff	0	34
1	Buff	2	30
3	Buff	6	22
5	Buff	......	......

The clay becomes hard at cone 1 (2100° F.), and shows no sign of viscosity at cone 5 (2246° F.). The underlying blue clay, which shows great shrinkage, shows also a lower temperature of vitrification, having apparently reached viscosity before the yellow clay has become hard. There was some tendency also towards the formation of black cores. At the brick yard, brick are molded with a stiff-mud machine, having a capacity of 30,000 brick per day.

Up the river from this deposit, there is good laminated clay near St. Cloud, but between the two deposits, a mile or more from the town of Hasty, is a deposit which appears to be similar but which behaves differently. Many of the brick check badly in burning. The sample taken slakes in 3 minutes and is very highly plastic, requiring 36 per cent of water for molding. It shows an air shrinkage of 10 per cent and, even when carefully dried, shows a tensile strength not over 10 pounds per square inch, indicating that the shrinkage had caused cracks which weakened it. Burning tests are as follows:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
06	Salmon	2	22
05	Salmon	2	24
03	Salmon	3	21
1	Greenish yellow	10	5

The clay becomes hard at cone 06 (1886° F.), and had not yet reached viscosity at cone 1 (2100° F.). Apparently the only difficulty with the clay is the tendency to crack on drying, though there may be some serious trouble from the laminated structure due to the auger machine, which is used in the manufacturing. These difficulties could be easily remedied if a more sandy layer could be found for mixing with the clay now used.

At Annandale in the western part of the county, the Annandale Brick and Tile Company have built a plant on the Soo Line a mile east of town to use a deposit of laminated clay known to cover several acres, with a thickness of at least 15 feet. It is covered only with soil and has but few limey or ferruginous concretions. Traced for 200 yards eastward along the track, it is found to be very much more sandy and of inferior quality. The clay where used is found to contain sufficient sand, so this sandy part of the deposit remains untouched. In working and burning qualities, the clay seems to be excellent, but some difficulty has been encountered at the plant in getting the clay to dry without cracking.

In Sec. 27, T. 120 N., R. 25 W., which is about two miles and a half from Buffalo and a mile and a half from the railroad, there is a rather extensive swamp which has been drained by a state ditch. The material thrown out from this ditch contains fragments of shale in great abundance, and it is relatively free from limestone. It is noticeably different from the gray drift as generally developed. Such material has not been noted in the present work in any other part of the State except in the neighborhood of Alexandria. The clay slakes at once, and is highly plastic, requiring 25 per cent of water for molding. Its air shrinkage is 5 per cent and its tensile strength is 150 pounds per square inch, though it checks rather badly on drying. Burning tests by the Minnesota School of Mines Experiment Station gave the following results:

Cone No.	Color	Per Cent Shrinkage	Per Cent Absorption
04	Red	.5	17
02	Red	1.5	16
1	Red	2.5	14
3	Red	4.0	11
5	Red	......	......

The clay becomes hard at cone 02 (2030° F.), and shows no sign of becoming viscous at cone 5 (2246° F.). It has thus a range of over 200° F. during vitrification, and the cross fracture of a well-burned brick suggests that it would be good material for paving brick. Simple laboratory tests show that it is both hard and tough. The deposit appears to warrant further prospecting.

A lake deposit is formed along the shores of Lake Mary, 6 miles from the station of Howard Lake. The material is mixed with coarse sand available in the same neighborhood. Soft-mud red brick are manufactured at the rate of 250,000 per year.

At Monticello, brick were made some years ago from a very sandy clay in the banks of the Mississippi River which is probably alluvium. The deposit seems to contain less than 20 per cent of clay substance, and yields a common red brick of poor quality.

YELLOW MEDICINE COUNTY

Yellow Medicine County is covered with gray drift. Brick were once made near the town of Yellow Medicine.

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