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CLAYS AND SHALES OF MINNESOTA

BY

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CONTENTS.

ILLUSTRATIONS.

OUTLINE.

This bulletin comprises a discussion of 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 exactness to determine for what purposes they may be used. Detailed results of these tests are arranged by counties.

The technical terms used in the discussion are briefly explained in the sections on " Physical properties " (pp. 20–40) and " Technology " (pp. 49–67). Washing and mixing clays are processes recommended for experiments in technology.

Certain areas are recommended for prospecting and development. Refractory residual clays and kaolins are found in the central and southwestern parts of the State. Semirefractory clays are somewhat more widely distributed and should be sought by drilling. The area of Decorah shale in southeastern Minnesota is mapped in detail. The upper Huronian slates near Duluth may be found worthy of development, as it is believed that excellent fancy brick can be made from them by a small addition of red-drift clay.

The general character of each geologic formation and the character of the clay products made from it by the several methods of manufacture are set forth.

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

Deposits suitable for common brick are abundant and widely distributed in many accessible localities in the eastern part of the State. The red laminated clay of the eastern counties makes good red brick and may be used as a slip glaze for semirefractory ware.

The Minnesota products are not inferior to those now brought in large quantities from Wisconsin, Iowa, and Illinois at unnecessarily high prices.

CLAYS AND SHALES OF MINNESOTA.

By Frank F. Grout.

INTRODUCTION.

SCOPE OF PAPER.

This bulletin gives the results of an investigation of the clay resources of Minnesota made during 1912 and 1913. In general the object of the work has been to assist in the development of the clay resources of the State. The broader problems of ceramics are treated only incidentally, but 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 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 be published later.

Specifically, the object has been to investigate the brick supply for every town of 1,000 or more inhabitants and for every county in the State, to ascertain the extent of several deposits now developed at only a few points, to find new deposits, and to determine the qualities of these deposits and of certain mixtures so as to ascertain whether it is possible to produce refractory wares, pottery, paving brick, and other high-grade products.

ACKNOWLEDGMENTS.

The work for this report was done by the United States Geological Survey, in cooperation with the Minnesota Geological Survey. Mr. E. K. Soper assumed the responsibility for the field work and county reports for those counties south of Minneapolis and St. Paul, including the mapping of the Decorah shale. Mr. Soper also wrote the section on the technology of clays and cooperated in the preparation of the section on the geology of Minnesota.

Acknowledgments are given to Messrs. Oliver Bowles, G. L. Harrington, and F. M. Handy, who assisted in the work; to Messrs.

Frank Leverett, F. W. Sardeson, and A. W. Johnston, who contributed certain geologic data; to Mr. Jefferson Middleton, of the United States Geological Survey, for lists of producers and statistics of production; to the Bureau of Standards, for tests; to the Minnesota School of Mines Experiment Station, for firing tests; to the experimental engineering department of the University of Minnesota, for tests of the products; to Mr. J. G. Houghton, Minneapolis inspector of buildings, for tests of brick and tile; and to Dr. C. P. Berkey, for unpublished data. Illustrations of some modern clay-working machinery have been copied by permission from catalogues of the American Clay Working Machinery Co. and Chisholm, Boyd & White Co. The work in the field has been greatly facilitated by the friendly cooperation of the commercial clubs and other organizations of the several towns throughout the State and by the aid of many individuals. Sincere thanks are due to 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.

BIBLIOGRAPHY.

1880. Winchell, N. H., Preliminary report on the building stones, clays, limes, cements, etc., of Minnesota: Minnesota Geol. and Nat. Hist. Survey Misc. Paper 8.

Divides clays into three classes: (1) Ferruginous laminated clays of loess loam and river valleys deriving their iron coloring matter from the northeastern drift; (2) alkaline laminated clays of loess loam and river valleys charged with lime (enough to destroy the red color), which is derived from limestone of the northwestern drift; (3) Cretaceous alkaline clays, mentioned as occurring up the Minnesota Valley. Forty-two plants producing red brick and 18 producing lighter cream-colored or gray brick are mentioned. Cretaceous clays, then used in a few potteries, were recommended as probably deserving more extended use.

1884, 1888, 1899, and 1900 Minnesota Geol. and Nat. Hist. Survey Final Repts., vols. 1, 2, 4, and 5; issued subsequently to annual reports of progress.

Contain many references to clays.

1897. Sardeson, F. W., Glacial deposits of Driftless Area: Am. Geologist, vol. 20, p. 392.

Mentions loess deposits of southeastern Minnesota.

1902. Berkey, C. P., Origin and distribution of Minnesota clays: Am. Geologist, vol. 29, p. 171.

Groups the clays of the State as follows:

Residuary: (1) Kaolins from the Archean gneisses; (2) common residuary clays, grading into loess.

Transported: (1) Sediments—Huronian slate, Ordovician shale, and Cretaceous shale; (2) glacial—till, lake clays, and stream clays; (3) recent alluvium; (4) loess.

1906. Ries, Heinrich, Clays: their occurrence, properties, and uses, New York, John Wiley & Sons.

Reports that the residual clays are of little value and emphasizes the Cretaceous clay of Red Wing and the widespread Pleistocene clays.

CLAYS IN ADJOINING STATES.

In North Dakota along the Minnesota boundary throughout a belt many miles wide brick plants have used the silts of Red River valley, which cover the drift so deeply that the lower formations are not well known.

In South Dakota the area along the Minnesota boundary is mostly covered with drift.

In Iowa, near the Minnesota boundary, the area, though mostly drift covered, is underlain by sediments ranging in age from Ordovician to Cretaceous. The most important clay product made from these sediments, so far as Minnesota is concerned, is the Mason City tile, made of Devonian shale. The Devonian rocks extend only a very short distance into Minnesota. The Cretaceous on the west and the Ordovician on the east are little used in Iowa.

In Wisconsin occur red-burning glacial deposits that extend a few miles into Minnesota along the greater part of the border. Red brick, such as that made at Grantsburg, Wis., is the main product of the widespread laminated clays. Loess covers a large part of the Driftless Area in Wisconsin and in southeastern Minnesota and overlaps the older drift to a certain extent.

GEOLOGY OF CLAY.

DEFINITION.

Clay is defined in two ways—as an earthy aggregate consisting essentially of kaolinite or some nearly related hydrous aluminum silicate and as any earthy mass that becomes plastic when wet. Usually a clay fulfills both these conditions. The mineral kaolinite has the composition $H_4Al_2Si_2O_9$; its specific gravity is 2.6. It is monoclinic in crystal form, white (unless impure), and insoluble in dilute acids, though decomposed by hot concentrated acids. Halloysite, pyrophyllite, cimolite, bauxite, and opal are often found in association 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.

MINERALS FROM WHICH CLAY IS DERIVED.

All or nearly all the clay minerals are secondary in origin, being formed by the hydrous alteration of other silicate minerals that make up the so-called crystalline rocks. The most common of these minerals are orthoclase (potassium-aluminum silicate), albite (sodium-aluminum silicate), anorthite (calcium-aluminum silicate), muscovite (hydrous potassium-aluminum silicate), biotite (iron-magnesium-aluminum silicate), and hornblende and augite (complex silicates, containing as a rule iron, magnesia, lime, and aluminum).

WEATHERING.

By various natural reactions some or all of these minerals are altered to kaolinite or related clay minerals. Orthoclase, albite, anorthite, and muscovite are of greatest interest, the others being of importance only because they introduce impurities into the resulting clays. The particular circumstances under which natural reactions produce kaolinite, especially in large bodies, from other minerals have been much discussed. Possibly the action of hydrofluoric acid may form kaolinite from orthoclase at great depths in the earth, but

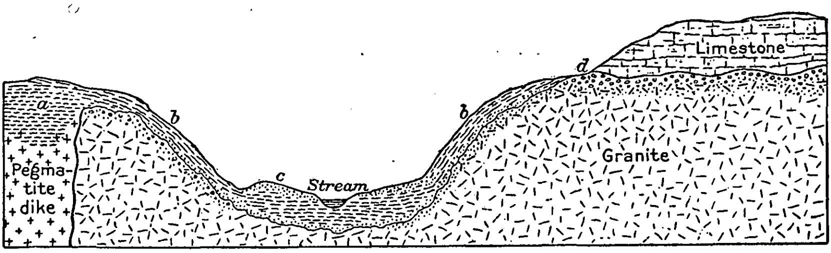


FIGURE 1.—Sketch showing the origin of types of clay. The primary rocks shown are granite, pegmatite, and limestone. Where these rocks have been long exposed to the weather the soluble constituents are more or less completely removed, leaving clays (*a*) and (*d*). The pegmatites are probably, in many places, partly altered before exposure and are deeply kaolinized. Clays of any sort exposed on a sloping surface are subject to wash by the rain, and such clays that have been transported short distances are known as colluvial (*b*). Clays carried by streams and deposited in a flood plain are alluvial (*c*).

it seems probable that little if any common clay has been so formed. The slower but more general action of weathering at the surface is of much greater importance, and kaolinite is the commonest product of such weathering, though under some conditions aluminum hydroxides may be the end products. (See fig. 1.)

Weathering is usually but not invariably accompanied by erosion and sedimentation. It includes both chemical effects, known as decomposition, and mechanical effects, known as disintegration, which are usually simultaneous and closely related. Many rock minerals are partly soluble in circulating water, and as a part of the mineral is removed, water may combine with the residue, producing hydrous minerals. These are usually softer and more loosely bound together than the original rock, and are hence more easily affected by mechanical processes, such as erosion by flowing streams carrying sediments, by wind-blown sand, or by ice, the pounding of the waves, and the unequal expansion resulting from alternations of heat and cold. All the mechanical processes break up rocks into finer particles and give the circulating waters easier access to the material and enable them better to bring about decomposition.

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

The results of rock weathering depend largely on the relative amounts of decomposition and disintegration. A powder formed chiefly by the breaking up of crystalline rocks must naturally have properties different from those of powders left by the chemical solution of part of the rock. One is termed "rock flour" and the other "rock rot." Glacial erosion, for example, is mainly mechanical and yields rock flour. The finest particles that result from weathering of either sort usually constitute a clay, which, from the nature of its formation, is likely to contain remnants of the original minerals from which it was formed.

An elaborate discussion of weathering, with a bibliography, is given by Buckman.[1]

Comparison of fresh and weathered portions of two Minnesota rocks may be of interest, though each of the rocks is variable and it is not altogether certain that the altered rock is derived from one of exactly the composition of the fresh rock.

Analyses of fresh and weathered rocks of Minnesota.

	Granite gneiss of Morton.		Diabase lava flow of Pine County.	
	Fresh.[a]	Weathered.[b]	Average fresh.[b]	Weathered.[b]
Silica	63.61	60.61	57.65	43.38
Alumina	16.71	18.12	14.97	20.42
Ferric oxide	5.69	} 7.51	6.05	13.57
Ferrous oxide	2.78		4.23	....
Magnesia	1.63	1.14	4.00	5.17
Lime	4.03	.03	4.30	.27
Soda	1.68	.54	2.01	.35
Potash	2.49	3.56	3.18	5.46
Moisture	....	.28	.33	4.24
Combined water	.61	7.20	1.91	5.54
Titanium oxide	....	1.30	1.84	.92
Miscellaneous	....	....	.40	....
	99.23	100.29	100.87	99.29

[a] Analysis by A. D. Meads. [b] Analysis by F. F. Grout.

EROSION AND SEDIMENTATION.

The processes of erosion and sedimentation have a very intimate relation to the accumulation of workable clays. Particles of clay

[1] Buckman, H. O., Am. Ceramic Soc. Trans., vol. 13, p. 336, 1911.

formed by weathering are finer than those of sand and gravel and when washed by water are often separated from them. The carrying power of running water depends largely on its velocity, and 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 tends to cause the accumulation of large bodies of clay free from sand. Some streams flow fast enough at all seasons to carry both sand and clay, yet their burdens may be sorted where they reach a lake or the ocean; their currents are at first only partly checked and they deposit the coarser sand near shore and carry the clay farther out. Similarly, shore currents and waves separate sand from clay and may deposit the clay 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 or, on the other hand, may deposit mineral matter as cement or as concretionary masses. An analysis of a common type of concretion is given in the discussion of Anoka County (pp. 113–118). Again, an increase in temperature may dehydrate a clay and change the mineral combinations. Most clays accumulate in nearly horizontal tabular masses, but these masses may be folded or faulted by later earth movements.

In Minnesota the most notable alterations are probably the leaching and oxidation of the upper layers of the clay and the deposition of concretions at lower levels. By this process a glacial deposit of "rock flour" may become altered to a more plastic kaolinite or even to minerals like bauxite, with an excess of aluminum. Leaching may improve some clays by removing the lime. In the Red River valley only the upper layers of the clay, from which the lime has been leached, are serviceable for brick material. The leaching has also improved them by somewhat reducing their plasticity and shrinkage, which are still too great in the lower joint clays. On the other hand, the leached surface clays (gumbo) at Wrenshall and Princeton show too much shrinkage and are more plastic than the lower clays, which are much better for brickmaking, though they are higher in lime content and in some layers are injured by concretions. The widespread gray drift of the central part of Minnesota is commonly somewhat leached to a depth of a few feet; in some places it has been much improved by removal of the lime, but in most places weathering has merely oxidized the iron minerals, changing the color to a yellowish gray but leaving the other properties essentially unchanged. The gray unaltered clay has, if anything, greater plasticity and shrinkage than the altered clay. (See fig. 2.)

GEOLOGIC TYPES OF DEPOSITS.

RESIDUAL CLAYS.

The weathering and superficial decay of granitic igneous rocks have in some places produced a sheetlike mantle of clay of great lateral extent and as much as 100 feet thick. As a rule such deposits follow the irregularities of the original rock surface, their base depending more or less closely on 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. Still other residual clays result from shaly sedimentary rocks. The impurities depend largely on the completeness of the alteration. The analyses of Minnesota material given in the discussion of weathering (pp. 16–17) furnish an example of partial alteration.

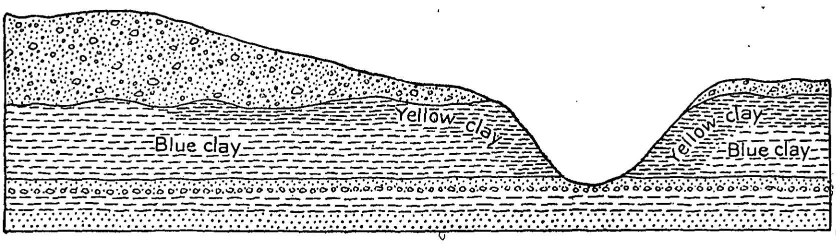


FIGURE 2.—Sketch showing the influence of thickness of drift overburden on the depth of weathering of clay. Many blue-gray clays weather yellow when the organic matter and iron are oxidized and the lime leached out. This weathering affects even some clays that are buried under drift; but if the drift is thick, the oxygen and leaching solutions do not reach the clay so freely.

Some kaolinite is present in the altered rocks, and all such residual clays that burn white are called kaolins. Ries[1] has summarized the theories of the origin of kaolins.

TRANSPORTED CLAYS.

MARINE DEPOSITS.

Sedimentation in the sea, usually at a distance from the shore, produces clay deposits which tend to have great lateral extent as compared with their thickness. Both horizontally and vertically the clay body may grade into limestone or sandstone, and vertically it may alternate with these rocks. In Minnesota the Decorah shale is a good illustration of such alternating beds. Subsequent concretionary action may add to the impurities; or leaching, under favor-

[1] Ries, Heinrich, Am. Ceramic Soc. Trans., vol. 13, p. 73, 1911.

able conditions, may decrease them. If later marine formations cover the clay deeply, their pressure may consolidate the clay into a shale. If the shales are later exposed by erosion, they weather back into soft clays.

LAKE CLAYS.

Lake clays originate in much the same manner as marine clays, the chief difference being in their extent. The clays near Heron Lake, Minn., seem to have originated as lake deposits.

ALLUVIAL CLAYS.

Rivers that carry large amounts of fine sediment vary in the rapidity of their currents at different times and in different parts of their channels. Where flood waters spread over the bottom lands and where an eddy or other irregularity reduces the current very greatly sandy clays are likely to be deposited. These conditions are most common along the wide flood plains of the larger streams.

GLACIAL CLAYS.

The glacial drift as carried by the ice may have only a small proportion of clay, but this small proportion may be concentrated into valuable deposits by the flow of water from the melting ice.

The abrasive action of the ice has in some places ground up considerable amounts of rock to a fine powder that has not been extensively decomposed. This so-called rock flour has many of the properties of clay and has been used as a brick material. It appears that in some places decomposition has later turned some of this flour into kaolinite.

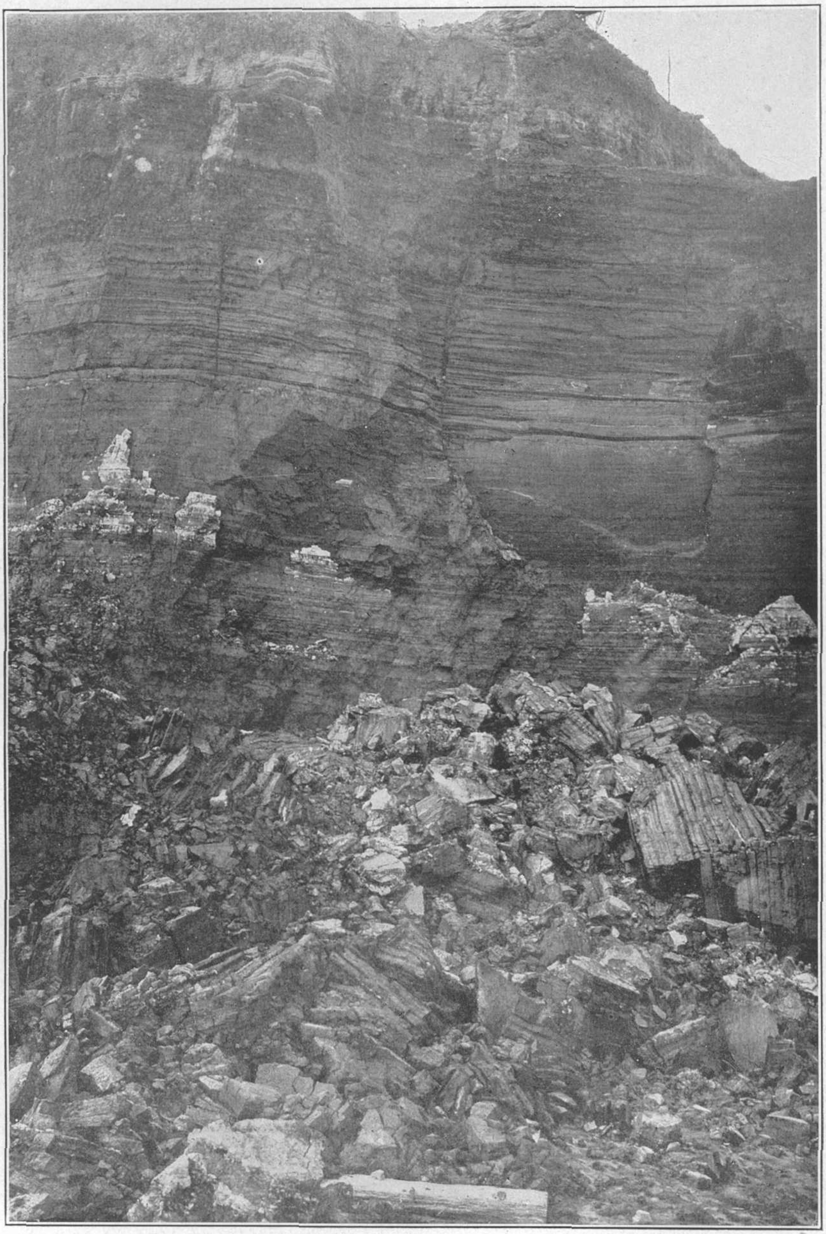
Many lake and alluvial clays of glacial origin resemble lake and alluvial clays that are not connected with glacial action, but they are of sufficient importance and extent in Minnesota to warrant separate mention. (See Pl. I.)

SLATES.

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

RELATION OF TYPES.

The several geologic types of clay are not always easily distinguished in the hand specimen or even in the field. Even the fundamental genetic distinctions between residual and transported clays



SECTION IN CLAY PIT AT WRENSHALL.

are often most difficult to apply, and there are many gradations between the several types. The origin of the clays as here outlined bears little traceable relation to their applicability as ceramic material. One marine shale may be a good fire clay and another a fusible slip clay without any ascertainable distinction in the mode of their formation.

MINERALOGIC AND CHEMICAL PROPERTIES OF CLAY.

Few clays approximate very closely the composition of the mineral kaolinite. Alteration of original minerals is seldom complete, and the residues contaminate the product. Transportation and deposition rarely exert such selective action as will yield pure kaolinite. Other minerals are deposited with the kaolinite, and after deposition many solutions affect the deposits, rarely in a way to improve its quality. Each of the modes of formation, however, has produced some very high grade clays and many notably useful deposits.

CONSTITUENTS OF THE CLAYS.

CHEMICAL COMPOSITION.

The chief chemical constituents of clay as estimated by common rock analysis are shown in the following table. Each constituent, whether abundant or rare, has a somewhat definite relation to the physical properties of the clays and the wares burnt from them, but any conclusions based on such analyses must be very generalized.

Approximate range in percentage of certain constituents in clays of several types, compiled from miscellaneous sources.

	Brick clay.		Pottery clay.		Fire clays.		Paving-brick clay.	
	Maximum.	Minimum.	Maximum.	Minimum.	Maximum.	Minimum.	Maximum.	Minimum.
Silica	91	34	87	45	97	35	70	55
Alumina	44	10	35	14	40	2	25	11
Iron oxide	32	0	7	0	3	0	9	2
Lime	15	0	10	0	2	0	3	0
Magnesia	7	0	5	0	1	0	3	0
Alkalies	15	0	7	0	3	0	4	0

ESSENTIAL CONSTITUENTS.

SILICA.

Silica (SiO_2) is present in the clays in a variety of forms. As quartz it is free from chemical combination. It is an essential constituent, forming 46 per cent of the kaolinite or the fundamental clay substance, and is prominent in the many silicates from which kaolinite may be derived and which form secondarily with kaolinite. Silica, therefore, usually constitutes more than 50 per cent of the clay. The highest amount of silica in the ordinary clay silicates (p. 15) is about 65 per cent in pyrophyllite, and if the silica approaches that figure some of it probably occurs free as quartz. It is not considered an active flux, though when mixed with kaolin it lowers the melting point considerably. In the form of sand it may have a beneficial effect on the clay in reducing excessive shrinkage and plasticity. Its compounds are as a rule hard and rocklike when anhydrous, and to them is due the hardness of burned clay.

ALUMINA.

Alumina (Al_2O_3) is also an essential constituent of kaolinite, of which it forms 40 per cent, a larger proportion than in any other common mineral. Some residual clays in Minnesota are exceptional in having more than 40 per cent of alumina. Lean sandy clays may have less than 10 per cent. Alumina is also present in most of the common clay silicates. As the basic element of kaolinite it is the most essential metallic element of clays and is in every way desirable. On it depend the properties of both raw and burned clay.

COMBINED WATER.

Combined water (H_2O) is the third important oxide in kaolinite, of which it forms 14 per cent, and it is found also in other minerals. As numerous anhydrous minerals are mixed with common clay, few analyses show as much as the theoretical 14 per cent of combined water. Burning expels it, leaving open spaces and thus increasing porosity. If it is very abundant sudden expulsion may cause "popping" or burst the ware into fragments.

NONESSENTIAL CONSTITUENTS (IMPURITIES).

MECHANICAL AND HYGROSCOPIC MOISTURE.

Oven-dried clay greedily absorbs moisture from the air in considerable amounts, even as high as 10 per cent of the dry weight. This amount of water in a clay powder seems to have no appreciable effect in making the clay appear moist. As dug from the bank most clay contains water in even larger amounts, as much as 40 per cent, in the capillary pore spaces between grains, without being very soft. The relation of water to clay is further discussed in connection with plasticity (pp. 30–32). A clay that remains firm with a high percentage of water is likely to shrink greatly in drying. If the water is not removed before firing it must be removed in the kiln. This delays to some extent the firing and the later oxidation.

LIME COMPOUNDS.

The most abundant form of calcium in clay is the carbonate, calcite ($CaCO_3$). This may be residual from the original rock or it may have been transported and deposited with the clay mechanically or by the action of organisms or by circulating waters. It may be finely disseminated or may occur in laminae, strata, or pebbles. Its effects vary with its condition.

If finely divided and disseminated in the clay, calcite acts as a flux. At some temperatures above 600° C. carbon dioxide is evolved, and the lime (calcium oxide) remaining acts as a powerful base, combining with the acidic elements of the clay, mostly silica, to form fusible salts. If the temperature is not high enough to effect this fusion and combination, the fine-grained lime remains in the burned product and after exposure may be hydrated (slaked) by the moisture of the elements without much harm. If the temperature is high enough to cause fusion, the lime becomes a dangerous ingredient, reducing the range between incipient fusion and viscosity. A high percentage of lime makes it impossible to produce vitrified ware safely, but the exact percentage of lime that is allowable for a particular product is not determined with certainty. Good clay for common brick may contain as much as 15 per cent of lime. If the proportion of lime is about three times as great as that of iron and if the temperature is high enough, the red color ordinarily resulting from iron is changed to buff.

Limestone pebbles in a clay cause more serious difficulties than finely divided lime. In burning, the pebbles give off large volumes of gas concentrated in certain spots, and the lime formed has a tendency to expand and destroy the ware. The temperature may be raised to the point where the lime reacts with the bases, but the pebbles are usually so large that reaction is only superficial. Before they are completely vitrified most bricks would be softened to a viscous condition. Worst of all is the effect of the lime formed from the pebbles after burning. As the brick is exposed to moist air or weathered, the lime hydrates and swells. Very small grains do not disrupt the ware, but pebbles can break even a large well-burned brick; and many kilns of clay containing them have been burned without the production of a thousand satisfactory brick. To avoid these disastrous results, several processes, all of which involve added expense, have been devised. (See pp. 55–57.)

The variations in the mineralogic and physical condition of the elements in a clay make it impossible to predict with certainty from an analysis how the clay will behave in the fire or what will be the value of the burned ware. The following table gives analysis of the gray drift as dug from the ground, unfit without washing for brick or tile, and of a good clay that can be sent directly to the brick machine. With the analysis of the original clay dug at Hutchinson (No. 1) may be compared that of the average clay used, after washing, as given in the section on McLeod County (p. 193).

Analyses of calcareous clays.

	Pebbly clay.[a]	Fine-grained clay.[b]
Silica	58.85	53.32
Alumina	7.25	8.87
Iron oxides	4.97	4.71
Magnesia	3.45	6.62
Lime	9.42	9.21
Soda	1.37	6.60
Potash	1.76	2.26
Ignition	11.20	6.07
Moisture	2.10	1.94
Titanium oxide	.36	.37
	100.73	99.97

[a] Hutchinson gray drift; requires washing to remove pebbles before use.
[b] East Grand Forks, silt of Red River valley; used without treatment.

Besides this uncertainty as to the effect of the lime reported in analyses, due to textural differences, there is a variation in the effect of lime, due to the presence of other impurities and the proportions of the several oxides, even if the textures are uniform. If two substances like lime and clay combine to form a fusible mixture, the particular mixture which fuses at a minimum temperature is called a eutectic. An excess of lime over the proportion required for a eutectic mixture will not flux so actively as the eutectic proportion. Therefore, the amount of lime that is most injurious in clays is uncertain and varies with the other constituents, but the proportion of lime that commonly results in rapid vitrification is stated to be from 2 to 8 per cent. Very few clays containing more than 15 per cent of lime can be utilized for ceramic products of any sort, but it has been demonstrated in practice that certain clays containing a much higher percentage make good common brick. No such clays are known in Minnesota, however, and a high proportion of lime is taken as a sign that the clay is unfit for brickmaking.

If the lime is present in the clay as a silicate, such as hornblende, instead of as the carbonate, calcite, the eutectic will contain other ingredients and vitrification may be more gradual. Iron and the alkalies, if present, also affect the fusion of lime and clays, making it still more difficult to predict their behavior. Lime is never added to improve a clay, though small amounts of calcareous clay might be added to some of the Minnesota fire clays to strengthen the brick.

Gypsum, the sulphate of calcium ($CaSO_4$), may be an original constituent of clays or it may form in clay by a reaction of sulphuric acid from iron sulphide minerals on crystals or veins of calcite. At high temperatures its effect on fusibility is much the same as that of calcite. It may produce an efflorescence in burning or after exposure to the weather. A careful study of the effect of gypsum on clays has been made by Kramm.[1]

IRON OXIDES AND SULPHIDES.

Iron is the main coloring element in clays, both raw and burned. Its compounds are easily fused and form easily fusible mixtures. Iron combines with oxygen in several proportions in hematite, limonite, magnetite, and the silicates. Hematite or ferric oxide (Fe_2O_3), more or less hydrated, is the most common. In vitrification its effect on clays is generally good, as it causes only a gradual softening of the heated mixture. Many analyses of clays show both ferrous and ferric oxide, but this is not of special importance, for in burning, after the early oxidation stage, all the iron is in the ferric form. It can be oxidized or reduced at will, by regulation of the fire, and color and fusibility of the product vary with the treatment it receives. If much organic matter is present, the oxidation of the iron may be delayed and the ware may be entirely ruined by the persistence of the ferrous compounds which differ greatly from the normal ferric compounds in fusibility and color. The total iron oxide in clays ranges from a trace to over 30 per cent. The coloring and other effects it produces are complex and are discussed in the paragraph on heat effects.

The carbonate of iron, siderite ($FeCO_3$), and the several sulphides of iron, largely pyrite (FeS_2), are somewhat more fusible than the oxides, but if the temperature is raised slowly they give off their acid vapors and become ferric oxide.

MAGNESIA.

Magnesia is a common constituent of the original silicates from which impure clays are derived, but most of the magnesia is removed in solution by weathering, and only traces of the silicates are usually found. Along with the calcium carbonate, some clays contain magnesium carbonate, apparently formed by reaction of circulating water solutions on the calcite. Dolomite, a mineral containing both calcium and magnesium, is common in Minnesota, and its effects may be assumed to be much like those of calcite. Magnesia does not

[1] Kramm, H. E., Effects of gypsum on clay: Am. Ceramic Soc. Trans., vol. 13, p. 703, 1911.

increase the rate of vitrification so much as lime, nor does it destroy the red color of the oxidized-iron compounds so readily as lime. Sulphate of magnesium is a soluble salt which is sometimes reported in clays and which is capable of producing an unsightly efflorescence.

SULPHUR.

Sulphur occurs in iron, calcium, and magnesium compounds. In whatever form it is originally present in the clay, it soon becomes oxidized in the kiln, forming the gases SO_2 and SO_3 and, if metallic oxides are available, compounds known as sulphates. The gases formed must escape, even from the interior of a brick, and sometimes the sudden expansion, due to the escaping gases, does some damage. The sulphates formed are largely soluble, and if the temperature is not high enough to destroy them they may cause unsightly efflorescences. At a temperature of 800° C. more than half of the sulphur is given off and above 800° C. part of the remainder is very slowly removed. At the vitrification point the sulphates are mostly destroyed and gases given off. These gases may cause swelling and "bleb" structure. Pyrite (FeS_2) and gypsum ($CaSO_4.2H_2O$) occur in the Cretaceous and Decorah shales of Minnesota.

ORGANIC MATTER.

The organic matter scattered in the clay is usually of a peaty or bituminous nature and is lower in specific gravity than most minerals. It may give the clay a color ranging from green or blue to black or brown. It is thought by some that organic matter in colloidal form is the chief cause of the plasticity of clays and their dry tensile strength, but the relation is still uncertain. Much organic matter may accompany lean, weak clays.

In the burning process organic matter disappears, forming carbon dioxide and water vapor at temperatures depending largely on the supply of air. During its combustion it acts as a fuel and may cause a sudden rise in temperature. It has more affinity for oxygen than iron has, and it usually burns out completely before iron is thoroughly oxidized. It is this relation to the oxidation of iron that makes organic matter troublesome in certain clays. Furthermore, the removal of carbon leaves the clay mass porous and much lighter than it would otherwise be and causes a very high shrinkage when the mass is heated to the point of vitrification. If the ware is not to be vitrified, however, the porosity may be desirable, as it makes the product of lighter weight. For fireproof buildings, if an extra light brick is wanted, as much as 20 per cent of sawdust is often added to the clay to decrease the final weight.

TITANIUM, COPPER, MANGANESE, AND PHOSPHORUS.

Titanium, copper, manganese, and phosphorus are commonly present in clays in small amounts only, and their effects are not important. Experiments indicate that if exceptional quantities are present each of them has a decided effect on the quality of the burned clay. Titanium, the most abundant, commonly forms less than 1 per cent of the clay and affects the fusion point of pure fire clays only a few degrees centigrade.

Manganese compounds are the only ones of the group that are ever purposely added to effect changes in the product. One-fourth of 1 per cent of manganese will noticeably change the color of many wares. The changes commonly desired are from red to brown or from buff to gray. The usual procedure is to mix one part of powdered manganese dioxide and nine parts of clay with water into a thin slip, and to use this as a stock reagent to be added to the clay in amounts to be determined by actual practice. Speckled brick are made by using granulated instead of powdered manganese.

ALKALIES.

Soda, potash, and small amounts of lithia are reported in clay analyses. These are present as remnants or residuals of the original alkaline silicates from which the clay minerals have formed, as partial decomposition products and less abundantly as other salts. Most of them, such as the feldspars, are no more plastic than sand and have about the same effect on the raw clay, but some, such as the micas, are soft and slightly plastic. In burning, these alkalies act as powerful fluxes and cause a slow and very desirable kind of vitrification. For the highest grades of chinaware, orthoclase, the potash feldspar, is usually added in definite proportions. As orthoclase melts it forms a highly viscous fluid, whose viscosity decreases very slowly as the temperature is increased. It can thus be melted without rapidly losing its form. Other alkaline minerals behave similarly, but the exact behavior of each is not clearly understood. Potash is much the most abundant and soda next, but few clays contain lithia in determinable amounts.

STATE OF MINERAL COMBINATION.

The constituents mentioned above behave differently, according to their state of combination—that is, their behavior depends on the minerals which are present in the clay. The minerals observed in the clays of Minnesota are kaolinite and related aluminum silicates, pyrite (or marcasite), quartz, hematite, limonite, calcite, dolomite, siderite, hornblende, micas, gypsum, feldspars, chlorite, staurolite, rutile, and glauconite. Other minerals likely to be present are the oxides of manganese, as well as alum, epsomite, and zeolites. No systematic classification has been devised to indicate the minerals or elements present, but such terms as calcareous clays, ferruginous clays, and micaceous clays may be used to indicate the presence of impurities.

Rational analyses of clays are attempts to estimate by chemical tests the proportions of the several minerals contained. If a clay is of high grade and contains only a few minerals (except in minute traces) such an estimate is easily made by determining the percentage of the clay soluble in certain reagents and making a few simple chemical determinations. For example, potters have long used a combination of clay substance, feldspar, and flint, mixed according to some definite formula. By first treating the crude clay with hot concentrated sulphuric acid and later with a solution containing 5 per cent of sodium carbonate, the clay substance or kaolinite can be dissolved and its amount determined. In the residue of feldspar and flint the determination of either the alkali or alumina is sufficient to determine both minerals. Then the potter can add flint and feldspar to meet the requirements of the formula. When the flint, feldspar, and clay have been derived from similar sources and treated in similar ways, such an analysis gives easy and satisfactory control; but with a new clay deposit or a change in the grinding or treatment it will be found that materials having the same rational analysis will vary a good deal in behavior. If the clay is impure, containing as it may a dozen or more minerals, it is absurd and misleading to report the material as consisting only of clay, flint, and feldspar.

The flint is often reported as "free" or "uncombined" silica. For cement mixtures uncombined silica is less desirable than combined silica, and the rational analysis thus serves as a test of the availability of a clay for the manufacture of cement.

VALUE OF CHEMICAL TESTS.

Chemical tests can determine very little as to the applicability of clay to any specific purpose. Certain general relations may, however, be stated:

1. High-grade clays, suitable for use in making refractory ware and as kaolins, should show nearly the percentages of alumina and water shown by kaolinite and should not be too high in silica. They should contain little else. Commonly accepted though arbitrary and not wholly reliable limits place the permissible total content of lime, magnesia, and alkalies at not over 4 per cent and of iron oxides at not over 3 per cent.

2. Fusibility is more or less closely related to the amount of impurities, and the relation is useful even if inaccurate, especially in considering refractory clays. In general, the greater the total sum of fluxing impurities the more fusible the clay. Detailed calculations are seldom of value.

3. The color of burned ware can be roughly foretold from the amounts of iron and lime. Clays with 3 per cent or more of iron oxide tend to burn red, unless an excess of lime is present. Other matters are involved, as for example the evenness of distribution and fineness of the grain of the iron and lime and the character of the gases in the kiln.

4. The shrinkage is related in some indefinite way to the water content. Usually a clay containing much hygroscopic water is plastic and has a high air shrinkage. A clay with much combined water and organic matter will show high fire shrinkage on vitrification. A high proportion of silica usually accompanies a rather low water content, low shrinkage, and low plasticity.

5. The rate of vitrification is likely to be undesirably rapid if as much as 5 to 10 per cent of lime is present, especially if the lime is accompanied by other fluxes.

6. Soluble salts likely to produce efflorescences are indicated by sulphur. Some analyses include estimates of "soluble salts."

7. The particular chemical constituents for making cement can be estimated.

8. A comparison of two clays of similar type can sometimes be made by one or two chemical determinations.

All except the last two of these relations can usually be determined more accurately, in less time, and at less expense by physical tests than by chemical tests. The physical tests are more accurate because the behavior of a clay varies not only with the composition but also with the texture and the combination of elements. For this reason not many analyses have been made for this report. Widespread types have been analyzed, however, and the effects of washing, both in practice and in laboratory tests, have been studied by analyses of all the materials involved.

PHYSICAL PROPERTIES OF CLAYS.

As clays are made up of many different materials, mixed in an infinite variety of proportions, it is to be expected that the range in their behavior and applicability will be great. Some of the qualities of the mixture called clay are extremely important and are the very foundation of most of its uses. These are plasticity when wet; shrinkage on drying; tensile strength when dry; behavior when heated, including temperature of fusion, rate of vitrification (temperature range), shrinkage and loss of volatile parts, and color and toughness (strength and hardness) of products; and miscellaneous properties, such as slaking, bonding power, specific gravity, porosity, fineness, feel, odor, taste, and homogeneity.

PLASTICITY.

By plasticity is meant ability to be molded, involving change of form without rupture, and strength to retain the molded form, so that when complex forms are built up they are self-supporting. By virtue of plasticity, clay is molded into and retains the forms required for great building blocks or preserves 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 anyone who has handled a great variety of clays can easily tell whether a clay is of high or low plasticity and can 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 define clearly, are readily felt by the expert and may affect the uses of the clay. It is common to speak of clays as "very plastic" ("fat" and "rich") or "nonplastic" ("lean" and "poor").

In practice, if a clay is too plastic it is too difficult to mold, and its plasticity must be reduced by the addition of nonplastic material, usually sand or burnt clay (grog). The preheating experiments of Bleininger showed a similar reducing effect on plasticity. (See p. 34.) If it is too lean a highly plastic clay may be added, though not always with satisfactory results; for instance, a plastic clay that is not refractory can not 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 be beneficial. 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 thus produced is uncertain, but probably it extends both to the fineness and to the proportion of colloidal matter. A third method is the addition of alkalies, acids, salts, organic colloids like tannin, or other solutions.

In "tempering a clay" (preparing it for molding) water is usually added according to the judgment of the worker. Some clays are of proper consistency when dug from the pit. Different clays and different processes of molding require different proportions of water. The percentage of water present at the proper consistency for molding 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 because a large amount of it indicates a tendency to crack on drying.

Plasticity is of such fundamental importance that its origin and causes have been the subject of much investigation. The minerals from which clays are derived are not notably plastic; neither are the majority of residual kaolins as first formed. No particular proportion of a certain chemical element, no particular physical property, and no particular geologic process has been determined to be necessary for the development of plasticity in wet clay. Yet no other mineral powder is so plastic, and no other has been made so plastic by the addition of reagents.

Study of the plasticity of clay must be directed, first, to finding an explanation of the ability of the clay to flow without fracture, and, second, to finding an explanation of its strength or resistance to flow, even when it can be molded by the use of force.

The flowage is ordinarily thought to be due to the water added. It is well known that the addition of water to any fine powder lubricates it, and if enough is added the whole mass becomes somewhat fluid and can be molded. This seems to be generally agreed upon and understood. Disagreement arises, however, in explaining the strength of the wet mass. Water has so little viscosity that it would seem at first glance that enough water to cause lubrication would result in very slight viscosity—no strength at all.

For the strength shown by wet clay two explanations, and thus far only two, have been offered, and both are explanations of the conditions under which water is rendered more viscous than in its ordinary state. One theory explains the increased viscosity of the water as being due to dissolved material and, as dilute solutions of ordinary matter are not very viscous, to colloidal solutions—solutions of the particular form of matter known as colloids. This theory has met with widespread favor. The other theory attributes the viscosity of the water to a strong attraction between the clay grains and water, called molecular attraction, which is active through only a short distance.

The colloid theory is based largely on the known presence of colloids of some sort in a clay;[1] on the analogy between some of the properties of clay, such as hygroscopicity, adsorption, and dry tensile strength, and those of some colloids (mostly organic); and on the fact that the addition of colloids improves the plasticity of lean clay. But, as opposed to a full acceptance of this theory at present, no one has yet shown that the colloids in a clay are quantitatively sufficient to produce the results. Neither has anyone succeeded in making a

[1] Schloessing, T., The constitution of clays: Compt. Rend., vol. 69, pp. 376, 473, 1874. Grout, F. F., and Poppe, F., Plasticity of clay: Am. Ceramic Soc. Trans., vol. 14, p. 71, 1912.

nonplastic mineral powder as plastic as common clay by the addition of colloids. The colloids in clay no doubt improve the plasticity and may be considered as a partial cause of it.

The molecular-attraction theory is based on the fact that when a liquid wets a solid a very thin film of liquid adheres to the solid so strongly as to be practically bound and is certainly rendered infinitely more viscous than the water outside the film.[1] A calculation in some detail [2] shows that the amount of water required to produce such a film around each clay grain and fill the pores between such enlarged grains is about equal to the water usually added in tempering. The calculation, however, applies to any fine mineral powder, and it remains to be shown why the viscosity should be greater with clay than with other minerals. The essential fact at the basis of the theory is that molecular attraction varies with the nature of the solid and liquid involved and seems to be greater between clay and water than between other minerals and water. Changes in plasticity on the addition of chemicals may be ascribed to changes in the nature of the solutions, and consequently in the molecular attraction. This also explains why some kaolin is plastic and some lean, for it is the chemical constitution (as distinct from composition or elements present) that determines the attraction. The molecular attraction, on which this theory is based, seems to be quantitatively sufficient to explain plasticity. As factors that modify plasticity colloids are probably of first importance. Fineness and shape of grain also have their influence on the amount of water bound in the viscous films.

SHRINKAGE.

The attraction between clay grains and water is so great that it is usually assumed that in plastic clay a film of water envelops each clay grain. The drying of such a clay would naturally affect 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, being filled with air instead of water. However, under ordinary conditions, capillarity draws water from the center toward the drier outer part, and the lubricating action of the water allows a slight readjustment in the whole mass. As a total result the same amount of clay remains with a smaller amount of water, the film 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

[1] Daniell, Alfred, A textbook of the principles of physics, 3d ed., p. 306, Macmillan Co., 1911.

[2] Grout, F. F., and Poppe, F., op. cit., p. 75.

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 shrinkage or as 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 flat surface than from the edges, and the greater part of the shrinkage will be at right angles to the flat surface. Shrinkage ranges from 1 to 15 per cent linear measure and from 3 to 48 per cent volume measure.

In the arts the shrinkage of clay is important. If bricks or chinaware of a certain size are required, allowance for shrinkage must be made by molding them 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 faster than internal readjustment can take place. The rate of capillary flow varies with the fineness of the grains, the distance to be covered, 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 cracks on the surface of a mud flat. In the arts the process is called checking. If the shrinkage is great it may be necessary to dry masses the size of common brick with great care for a long time to avoid cracking. Many clays otherwise of good quality are now neglected because they check so badly on drying. Such clays, which are often spoken of as "joint clays," are, as a rule, highly plastic, but require much water to develop their plasticity. There is, however, no constant relation between shrinkage and plasticity. Sandy clays and flint fire clays and kaolins show little shrinkage. The accepted remedy for checking is the addition of sand, "grog" (burnt clay), or other nonplastic material—just such material as corrects excessive plasticity.

TENSILE STRENGTH.

The term "tensile strength" usually means the tensile strength of dry clay. The strength of wet clay is not tested except in so far as it relates to plasticity. Probably the measure of crushing strength would be more useful, as clay ware is more often subjected to pressure than to tension. Usually, however, 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 ranges from 30 to 350 pounds to the square inch: 100 pounds 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 one another strongly. The gluelike nature of any colloids that may have been in solution also manifests itself as the water is removed.

EFFECTS OF HEATING.

The effects of heating are so complex that the subject must be subdivided. Heating decreases plasticity, tensile strength, and shrinkage; drives off certain volatile products; induces important chemical reactions; causes progressive fusion, which can be studied at several stages; and affects the quality of the product, including its color, shrinkage, toughness, hardness, and strength.

PREHEATING.

Bleininger[1] has made an exhaustive study of the effects of temperatures up to 400° C., in the hope of finding a means for correcting the defects of clays that check or crack badly in drying. His results show that most clays after heating to 250° to 300° C. require less water to make them plastic and have less plasticity and air shrinkage. Subject to certain limitations, which are clearly discussed in the paper cited, preheating offers valuable commercial possibilities in Minnesota, for there are immense bodies of joint clay in the Red River valley.

EXPULSION OF VOLATILE MATTER.

Hygroscopic moisture is as a rule completely removed from the clay ware before it is placed in a kiln for firing. During firing a series of products is removed, whose nature depends somewhat on the impurities of the clay. The most prominent constituents driven out are water, hydrocarbons, carbon dioxide, and sulphur, each of which requires a different degree of heat for its expulsion. Oxygen may be driven off or combined with the clay, according to the conditions of firing. Firing at red heat increases the porosity without much change in the size or strength of the ware. A too rapid increase of temperature and evolution of gases may break the clay mass with an explosive violence that may injure the ware near by. Snapping of this sort is seldom troublesome if care is used in removing water. If it is really troublesome and can not be prevented by thorough drying, it may be lessened by preheating.

The burning of the organic matter in the clay produces heat, like the addition of more fuel, and may cause a sudden undesired rise in temperature. Iron should be oxidized at 500° to 600° C., yielding

[1] Bleininger, A. V., Effects of preliminary heat treatment on the drying of clays: Bur. Standards Bull., vol. 7, No. 2, 1911.

normally a red color if abundant, but the oxidation may be delayed if oxygen is excluded by the evolution of other gases. At a temperature somewhat higher than 600° C. the carbonates, chiefly calcium carbonate, 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 remains in sulphates like gypsum until very high temperatures are reached. If fusion begins before all these gases are evolved, the clay mass will swell and become vesicular or "blebby" and be ruined.

CHEMICAL REACTIONS.

The oxidation and reduction of clays are complex, depending on the supply of fuel and air and on the temperature of the kiln as it rises to the successive fusion points of the several compounds present in the clay. Furthermore, reactions may produce a liquid from two solids which are in contact, even if the temperature is not high enough to melt either. The familiar example is ice and salt, which become liquid when mixed, at temperatures below the melting point of either. In clays lime and silica are examples of such substances. The fused material later acts as a solvent, which absorbs other minerals and which at this high temperature in fluid or semifluid condition is chemically more active than before. As silica is usually the chief acidic oxide present, the main products are silicates of indefinite mixed composition. After firing, these melted silicates solidify, forming the cementing material between the more solid grains and giving the rocklike quality to the finished ware. To them is largely due the character of the final product; if they are tough, the ware will be tough; if brittle, the ware will be brittle; if too scanty, the ware will be soft; and if too abundant, the ware will be deformed or melted. It is probable[1] that the chemical nature of the melt largely determines its toughness, and that magnesia, iron, and the alkalies give a tougher product than lime.

FUSION.

The formation of the fused silicates is progressive, increasing as the temperature increases. The first liquid to form, if kept at the temperature of formation, may dissolve some considerable portion of the surrounding minerals without becoming less fusible. If the temperature is raised, other minerals and combinations become fused and dissolve still other materials.

The fusion of the clay is therefore to be studied as a progressive and not as a sudden change from solid to liquid. Three stages are

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[1] Grout, F. F., and Brown, H. H., Relation of composition and properties: Am. Ceramic Soc. Trans., vol. 14, p. 355, 1912.

usually noted—incipient fusion, vitrification, and viscosity. The "temperature of fusion" is usually considered to be that of viscosity under no load. Fusion under load [1] is a test applied only to refractory clays.

At incipient fusion only the minerals and combinations with the lowest melting points are fused. If the fused parts are abundant, the whole mass, when cooled, will form a steel-hard product, so that hardness of the product is the common sign of incipient fusion. This degree of fusion causes very little shrinkage. Common brick usually require no further heat, and fire clays are not often burned even to this stage.

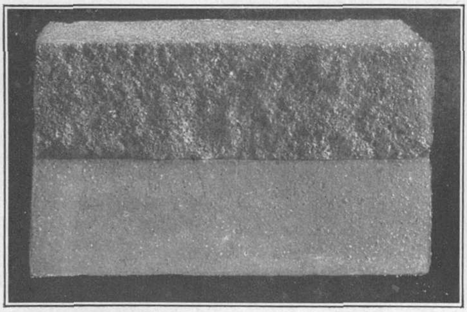
At vitrification enough of the clay has fused to fill nearly all the pores between the unfused grains, but unfused material is still abundant and the fused portion is so viscous that the ware keeps its shape. Shrinkage is usually high. A large amount of high-grade ware is burned to or very near vitrification. Porcelain and chinaware bodies, flooring tile, paving and foundation brick, and sanitary ware are usually vitrified, and some also receive a glaze, which makes the ware quite impervious to water. Many vitrified bricks are used for ordinary building, as they are more durable and resistant than common brick, and some have better color.

At a still higher temperature the clay becomes viscous, its unfused particles being quite surrounded and suspended in the fused and liquid portion, and the mass flows, losing its original form. When brick piled in a kiln have been burned to the approach of viscosity they may stick together and, if not too greatly deformed, may be broken up into blocks of about the size and shape of brick with the rough, irregular surface of broken stone. Such brick can be used in producing many artistic effects and have become popular under the name "klinker brick." (See Pl. II, *A*, *B*.) The actual temperature of viscosity, commonly noted as the fusion temperature, varies widely.

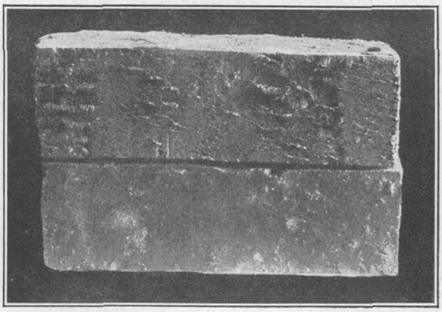
RANGE OF VITRIFICATION.

A most important point in determining the applicability of a clay to different processes of manufacture is the range of temperature between incipient fusion and the viscous state. In firing a kiln full of clay ware the combustion chambers can not be so distributed as to give absolutely uniform temperature throughout. Well-made, expensive kilns can approach uniformity very closely, but all are likely to show a variation of a few degrees. If it is desired to fire a brick to vitrification at 1,200° C., the top or bottom courses may

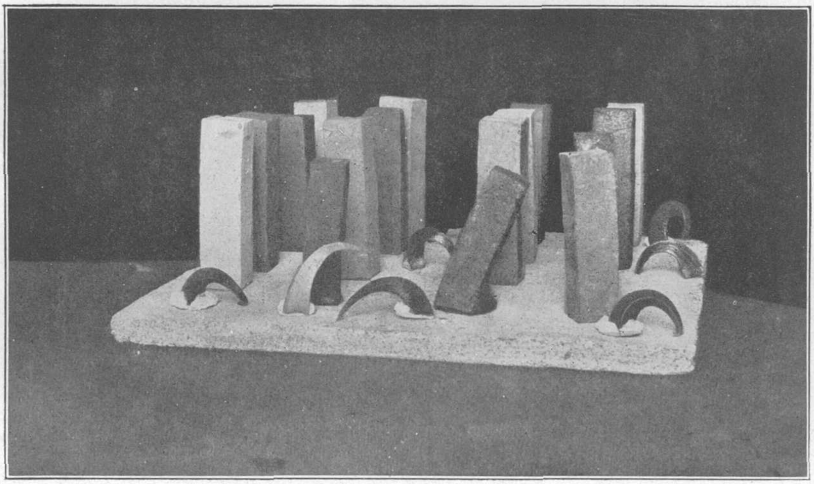
[1] Bleininger, A. V., and Brown, G. H., The effect of heating fire clays under load: Am. Ceramic Soc. Trans., vol. 12, p. 337, 1912.



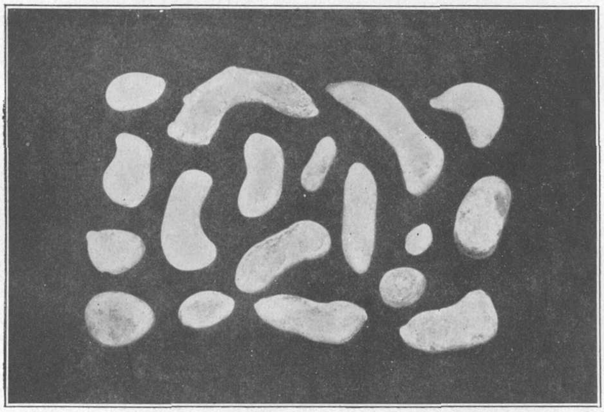
A. SMOOTH AND CLINKER BRICK FROM WEST ST. PAUL.



B. SMOOTH AND ROUGHENED BRICK FROM COON CREEK.



C. BRICKLETS BURNED IN LABORATORY TEST.



D. LIMY CONCRETIONS IN GRAY LAMINATED CLAY.

reach only 1,160° and the brick nearest the fire may reach 1,240°. If the point of incipient fusion is only 40° below the point of vitrification, the underburned brick will not be salable. But if the incipient fusion is 100° to 200° below vitrification there is every reason to expect that all the brick fired within 40° of the point of vitrification will be so nearly vitrified as to be entirely satisfactory. On the other hand, if the viscous state is reached at 1,240°, the brick near the fire will be waste, but if it is not reached for 200° after vitrification the brick burned to 1,240° will no doubt be of good quality. The losses due to underburning and overburning may be

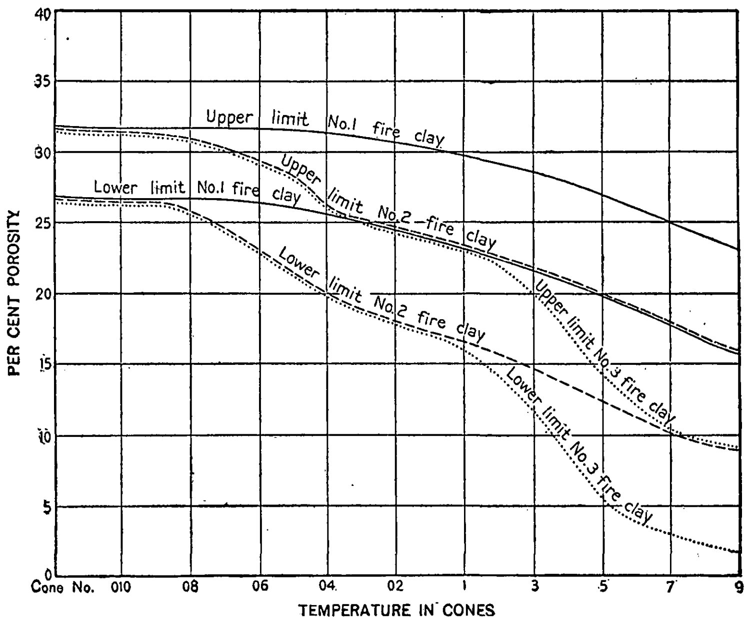


FIGURE 3.—Temperature-porosity curves for refractory and semirefractory clays. (After Purdy.)

as high as 30 per cent of the kiln. Underburned brick may be returned to the kiln, but they never equal brick directly fired to the proper point.[1]

The importance of determining the range in temperature during fusion has led to a careful study by Purdy [2] that resulted in recommendations for tests of porosity and specific gravity as a measure of vitrification. The accompanying diagrams (figs. 3 and 4) 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

[1] Grimsley, G. P., and Grout, F. F., Physical tests on West Virginia building and paving brick: West Virginia Geol. Survey, vol. 3, pp. 293–294, 1906.

[2] Purdy, R. C., Pyrophysical and chemical properties of paving-brick clays: Illinois Geol. Survey Bull. 9, pp. 277–278, 1908.

different temperatures and determining their porosities a curve showing the rate of vitrification can be drawn. This curve, if compared with Purdy's diagram, will indicate the applicability of the clay. In practice, however, the behavior of a clay is much more commonly judged by inspection of the bricklets burned to several different stages. A knife will easily show the steel-hard brick burned to the point of incipient fusion, and a glance will show the deformation of the bricklet burned to the viscous state. If these stages are widely separated in temperature, the clay can be safely

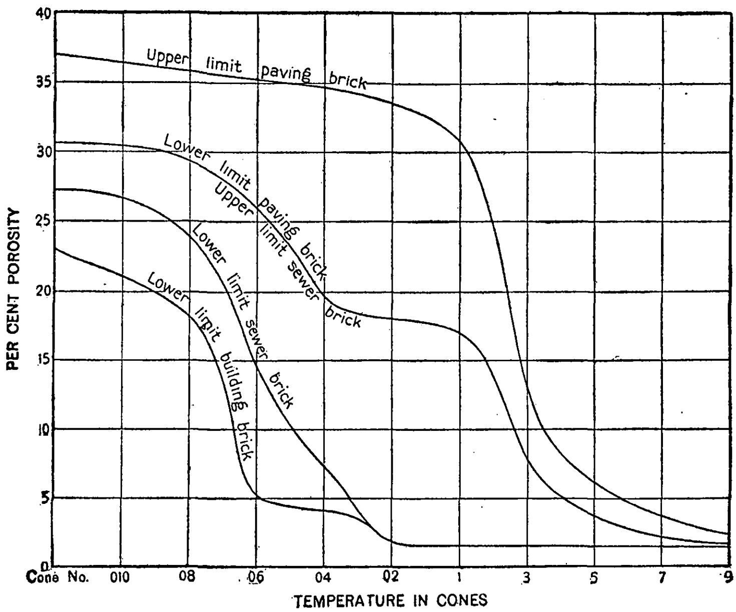


FIGURE 4.—Temperature-porosity curves for brick clays. (After Purdy.)

vitrified. The temperatures to which common clay wares are burned are shown in the following table in terms of Seger cones:[1]

Cone.	°C.	°F.	Cone.	°C.	°F.	Cone.	°C.	°F.	Cone.	°C.	°F.
022	590	1094	07	1010	1850	9	1310	2390	24	1610	2930
021	620	1148	06	1030	1886	10	1330	2426	25	1630	2966
020	650	1202	05	1050	1922	11	1350	2462	26	1650	3002
019	680	1256	04	1070	1958	12	1370	2498	27	1670	3038
018	710	1310	03	1090	1994	13	1390	2534	28	1690	3074
017	740	1364	02	1110	2030	14	1410	2570	27	1670	3038
016	770	1418	01	1130	2066	15	1430	2606	28	1690	3074
015	800	1472	1	1150	2102	16	1450	2642	29	1710	3110
014	830	1526	2	1170	2138	17	1470	2678	30	1730	3146
013	860	1580	3	1190	2174	18	1490	2714	31	1750	3182
012	890	1634	4	1210	2210	19	1510	2750	32	1770	3218
011	920	1688	5	1230	2246	20	1530	2786	33	1790	3254
010	950	1742	6	1250	2282	21	1550	2822	34	1810	3290
09	970	1778	7	1270	2318	22	1570	2858	35	1830	3326
08	990	1814	8	1290	2354	23	1590	2894	36	1850	3362

[1] Seger cones are small cones made of clay and chemicals so mixed that they soften at known temperatures, as indicated above. More accurate pyrometers are seldom needed in clay work.

Temperatures for burning common clay wares, in terms of Seger cones.

	Cone.
Common brick	012–01
Hard-burned common brick	1–2
Buff-faced brick	5–9
Fireproofing	03–1
Terra cotta	02–8
White earthenware	8–9
Fire brick	5–14
Porcelain	11–13
Sewer pipe	3–7

QUALITY OF THE PRODUCT.

The several steps in the process of heating have important effects on the quality of the product. Color is due largely to the content of iron or manganese, but in the firing it is modified by the oxidizing or reducing gases and by the degree of vitrification. Shrinkage becomes notable at the beginning of fusion, is complete at thorough vitrification, and may be replaced by swelling if gases are evolved after the formation of much glass. Hardness, strength, and toughness are all low until fusion begins; after that they depend on the quantity of glassy cement produced until vitrification is reached; after that they depend on the character of the glassy cement. Lime pebbles are causes of very serious difficulty. (See p. 23.)

MINOR PHYSICAL PROPERTIES.

Slaking is the quality by which a dry lump of clay tends to absorb water and fall to pieces when immersed. Clays that slake promptly are easily rendered plastic without fine grinding.

Bonding power is the ability of a clay to hold in suspension less-plastic material and to render the whole mass plastic and strong. It is usually though not invariably good if plasticity is high.

The specific gravity, porosity, fineness, feel, and color of raw clays may bear some relation to their availability for certain uses, but no one has yet discovered a system by which any useful property may be judged from these qualities.

Fineness of grain probably affects the fusibility and rate of fusion of impure clays but is less effective in high-grade clays.[1] The particles in a clay range in size from less than 0.001 millimeter to the size of a coarse sand. In general the finest particles approach the composition of kaolinite, though in some clays lime and iron also concentrate in the fine portions. The coarser particles are in general more siliceous.[2]

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[1] Hofman, H. O., Am. Inst. Min. Eng. Trans., vol. 28, p. 440, 1898.
[2] Grout, F. F., West Virginia Geol. Survey, vol. 3, p. 61, 1906.

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.

CLASSIFICATION AND ADAPTABILITY OF CLAYS.

CLASSIFICATION.

BASIS.

Clays have been differently classified for different purposes. Commercially, use is the basis of class names. Geologically, origin is most important. Technologically, the properties of the clay are the best points of distinction. These methods of classification are here kept distinct, as the combination of several methods nearly always results in confusion and overlapping groups.

CLASSIFICATION BY USES.

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

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; draintile; paving brick; chimney flues; chimney pots; door knobs; fireproofing; terra cotta lumber; copings; fence posts.

Hygienic.—Closet bowls, urinals, 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; electric porcelain; foot rules; plaster; alum.

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

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

Some of these uses are of sufficient importance to give class names to clays, as follows:

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

[1] Ries, Heinrich, and Kümmel, H. B., Clays and clay industry in New Jersey: New Jersey State Geologist Final Rept., vol. 6, pp. 213–214, 1904.

These terms are never used in a restricted sense. The same term may be applied to widely different clays, and different terms may be applied to similar clays. It is hoped that these terms will be used less as the properties of the clays become better known.

CLASSIFICATION BY GEOLOGIC ORIGIN.

A classification of clays by geologic origin gives the following:

- Residual:
  - From igneous and metamorphic rocks.
  - From sediments.
- Colluvial.
- Transported:
  - Marine.
  - Estuarine.
  - Lacustrine.
  - Alluvial (flood plains and terraces).
  - Glacial:
    - Till.
    - Lacustrine.
    - Alluvial.
  - Eolian, loess.
  - Metamorphosed slates.

CLASSIFICATION BY PHYSICAL PROPERTIES.

Classification by physical properties should be based primarily on the most important and secondarily on the less important properties. Plasticity, strength, and behavior in the fire are the major properties, and of these fusion is fundamental. If the plasticity or strength is insufficient it can be easily corrected by the addition of some proportion of other clay, but if the process of vitrification is unsatisfactory it is very difficult to remedy. Hence, the primary division should be based on heating behavior. The following classification, however, is not ideal, because there is some overlapping between the several grades of clay indicated:

	Main uses.
Refractory (fusing above cone 27):	
Earthy, usually residual, nonplastic	China clay.
Plastic	Ball clay and plastic fire clay.
Flintlike, nonplastic	Hard fire clay.
Semirefractory (fusing above cone 10):	
Vitrifying gradually:	
Red burning	Sewer pipe, paving brick.
Buff or cream burning	Stoneware.
Vitrifying suddenly	Low-grade fire clay.
Nonrefractory (fusing below cone 10):	
Vitrifying gradually:	
Red burning	Vitrified brick, foundation brick, sewer pipe.
Buff or cream burning	Foundation brick, sewer pipe.
Vitrifying suddenly	Common brick.

Subdivisions of semirefractory and nonrefractory clays may be based on their degree of plasticity.

SPECIAL CLASSES.

In addition to the comprehensive systems of classification special names are used to designate certain peculiarities. "Shale," one of the commonest, is used to indicate an indurated and generally laminated clay. The word is not applied to surficial deposits that have never been buried under later sediments, for few of these are laminated. Hardening (induration) is brought about by pressure, and cementation is effected by precipitation of mineral matter. The extreme of the hardening process is to be found in the development of slates, which are metamorphic rocks. Of those not classed as metamorphic rocks, probably the "flint clays" of the coal measures represent the maximum hardening. These may be grouped with shale, properly enough, though they are not usually so distinctly laminated as typical shale. Weathering reduces shale to its soft original state, probably by dissolving its cement. The term "slate" is incorrectly but very commonly applied to shales, especially to shales of the coal mines. "Soapstone" is applied, also incorrectly, to a shale that has a soapy feeling, which is probably due to a magnesian impurity. "Fire clay" is a miner's term for any clay below a coal bed, but as it is usually supposed to mean a refractory clay, its use to connote position is incorrect and confusing. Joint clay is very fine grained plastic clay which shows so great a tendency to shrink on drying that it almost invariably cracks. A great many adjectives, such as calcareous, ferruginous, and micaceous, are used to designate conspicuous impurities. It may also be worthy of note that geologic age is often used as a criterion for distinction, as Archean, Cretaceous, and Pleistocene clays.

Knowledge of the qualities that are essential in the clay for the production of certain grades of ware is most important for one who is about to develop a deposit. These qualities can be only briefly and in some cases not very definitely stated. The relation between the various systems of naming a type of clay and its uses is not always definite. Each system is of value, however, in its proper place. The physical properties are the most necessary to ascertain. The effects of impurities are discussed on pages 22–27. The age of a clay is worthy of note, chiefly as a help in finding more deposits. Ancient clays are much like recent ones, but in general the older formations are igneous or metamorphic, and the only clays they contain are either much altered slates or the residual products formed by recent decay of the old rocks.

The relation between mode of origin and properties or uses is equally indefinite. Residual clays formed from igneous rocks vary with the completeness of alteration and the character of the original rock. If thoroughly altered they contain little, if any, of the original minerals except quartz; iron oxides and muscovite are abundant impurities. If iron oxide is lacking, the kaolinite can be washed clean and used for china ware, though nearly all of it requires some plastic addition. Residual clays formed from sedimentary rocks differ somewhat from those formed from igneous rocks. Among transported clays the variety is great. In some parts of the country it is possible to find a transported clay that is suitable for almost any use to which clays are adapted. Estuarine, lacustrine, and glacial clays occur in similar variety. River clays are more likely to be sandy and impure, and will generally make nothing better than common brick.

True slates are seldom used in making clay products, but it is believed that excellent building material can be made from some of the Minnesota slates.

RELATION OF PHYSICAL PROPERTIES TO USES.

Common-brick clays should be capable of being molded into brick, should burn hard below cone 1 (2,100° F.), and should have a popular color. Somewhat higher plasticity is required for stiff-mud brick than for soft-mud brick.

Clay for front brick should be more plastic, so that the brick may hold their form better and present smooth surfaces and square corners. Their color after burning is more important than that of common brick. Front brick are nearly always burned steel-hard, and should have a good range of vitrification to avoid heavy losses from deformation.

Hollow brick and fireproofing blocks are made to attain 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. If the bonding power is good, it may be desirable to add sawdust to increase the porosity. The brick should have fair tensile strength. The color of the burned product 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 or density or beauty. Specifications for these products have been formulated and published.[1]

[1] Eng. News, vol. 47, p. 177, 1902.

Foundation, sewer, and sidewalk brick, which may be exposed to wet, freezing, and thawing, differ from common brick only in their degree of vitrification. They must be so well vitrified that water can not enter in such a way as to disrupt the brick on freezing. It should be possible to vitrify the brick very 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 material of the same type as foundation, sewer, and sidewalk brick, with an added toughness. This is even more important than completeness of vitrification and is attained with some clays by stopping the heat before vitrification is complete. As yet no way is known by which toughness of product can be inferred from the composition and properties of raw clays, and it is necessary to try them in actual practice.

Clays for draintile are similar to those used in making stiff-mud brick. The form of a tile is such that it tends strongly to warp and crack in drying. If a brick clay is free from this tendency and does not show auger laminations, it will probably make draintile.[1]

Wall and floor tile are made from buff-burning clays or white porcelain mixture, but more attention must be given to color, and, for some purposes, a special glaze is necessary.

Terra cotta clay must be very highly plastic and very strong to retain the complex ornamental designs into which it is worked. It is usually selected with great care to obtain uniform color and freedom from cracks. It should have a good range of vitrification but is only partly vitrified in manufacture.

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 necessary. Only a small amount of shrinkage is allowable, as warping and cracking are fatal defects. The dark product demanded by the market is usually obtained by adding a salt glaze.

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, and it is generally washed. It must be strong to hold its shape and must not shrink so much that it warps. It must burn white or very light and must partly vitrify without losing its form. The range in temperature between the beginning of its vitrification and the point where it attains the viscous state should be over 200° F. The product should be tough and strong. Much of it should be capable of receiving a glaze without being cracked and without subsequent breaking away of the glaze.

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[1] Tests for good draintile have been formulated by the American Society for Testing Materials (Proc., vol. 11, p. 833, 1911).

Refractory clays must primarily stand in the structure desired, at high temperatures, and they must withstand repeated heating and cooling without losing their strength and infusibility. Many of the refractory clays are nonplastic and few are burned to incipient vitrification. It has become a custom not to expect high plasticity of refractory clays nor much strength of the product. But if the brick are too weak, additions of plastic clay or bonding material must be made, even at the expense of fusibility. Fire brick are sometimes wanted with very coarse grain and open texture to prevent the rapid conduction of heat. Such brick are produced by the addition of large amounts of crushed burned clay ("grog"). For other purposes clay is desired that burns to a very strong, dense body at medium temperature and weakens or softens only at a very high temperature.

Clays for minor uses must meet varied requirements. Paper clay should be white, free from sand, and of good plasticity. Slip clay should be fusible and so fine grained that it will remain for a long time in suspension in water. Paint clay is so impure with ferruginous minerals as to have a dense color, usually red or brown. Adobe is any clay that will dry hard in the sun. Fuller's earth is an impure clay which has the property of absorbing coloring matter from oil. Deposits of several of these different types have been reported in Minnesota, but none have been much developed.

TESTS OF CLAYS.

SAMPLES.

All clay deposits visited in Minnesota were carefully sampled so as to get representative material. Pits were sampled by cutting a groove from top to bottom of the working face, and undeveloped deposits by boring several holes with a 2-inch auger. The samples taken for the Bureau of Standards weighed about 100 pounds and those for the University of Minnesota about 25 pounds. The results may be accepted as good indications of quality but are not by themselves sufficiently conclusive to warrant large investments.

CHARACTER OF TESTS.

Plasticity, strength, shrinkage on drying and burning, burned color, and character of vitrification may all be determined in the laboratory. If toughness of the burned product is essential, however, adequate data can not be obtained from a small laboratory sample and factory tests of carload lots are necessary. Factory tests should also be made on clays intended for glazed ware.

The following tests were made in the laboratory of the University of Minnesota, and the more important were checked by the United States Bureau of Standards with a somewhat better equipment.

Time of slaking of a half-inch dry lump was noted. The sample was then ground to 40-mesh, if it seemed desirable.

Plasticity was noted by feel and reported in six degrees—very high, fairly high, high, low, very low, and sandy.

Ten bricklets, 4 by 1 by 1 inch, were molded in a single brick mold, under a pressure of 300 pounds, one side being cut with a knife edge to get the proper dimensions. Volumes as made were fairly constant. Several briquets were made for tensile tests.

In measuring tensile strength no high degree of accuracy was attempted. Results usually differ for different operators, and as much as 30 per cent on different tests by the same operator. For this reason a test of a single briquet was sometimes considered sufficient, unless it showed exceptionally high or low results. Below 50 pounds to the square inch is considered poor; 50 to 150 fair; above 150 high. Correction must be made for shrinkage.

The effect of rapid drying on tensile strength was tested. The general effect of rapid drying is manifested by the appearance of cracks and checks and is commonly recorded as a personal judgment of the operator. Checks are supposed to indicate weakening of the briquet. In many of the university tests it was found by F. M. Handy that rapid drying was injurious to the strength of the briquet even when checks did not show prominently.

An adhesion test, developed by Mr. Handy, aims to show whether a clay loses tensile strength when forced through an auger brick machine. When clay products are molded on an auger machine the clay is mixed very thoroughly by knives and by the auger, both of which cut through the clay and press it forward through a die. In most clays the pressure is sufficient to join firmly the parts that have been separated in the machine. In some clays, however, the adhesion is much less than in others, and in some it is very poor. In the test worked out by Mr. Handy a newly molded tensile briquet is cut transversely, and then pressed in the molds at 300 pounds to see if a firm union can be effected between the divided parts. This is at least partly analogous to the action of the auger. None of the briquets so treated were of high strength, but those that showed defective auger structure had a tensile strength below 20 pounds to the square inch.

The molded bricklets were weighed when wet and again when oven-dried. The loss in per cent of dry weight was "water of plasticity." The use of oven-dry weights makes the reported water include hygroscopic water, and the totals are higher than the average reported by other investigators; however, this seems to be the only logical procedure, for the hygroscopic water is variable.

The volume of the dry bricklets was measured in a modified Seger volumeter, in kerosene.

Burning was conducted at several temperatures in a large gasoline-fired muffle measuring about 12 by 18 by 6 inches. The colors were nearly as bright as in actual practice. The bricklets were stood on end (see Pl. II, *C*) and may have begun to be deformed at a somewhat lower temperature than if they had been laid on one side. The temperatures were very nearly uniform through the muffle. The rate of heating and temperature reached were shown by a recording pyrometer and the use of Seger cones.

The burned bricklets were tested for hardness, color, and freedom from deformation.

Undeformed bricklets were weighed, boiled four hours in water, and weighed again, the difference showing the weight of water absorbed.

The volume of the saturated bricklet was measured in the volumeter, in water.

The porosity was determined by the formula

$$\text{Porosity (per cent)} = \frac{\text{absorption in grams}}{\text{volume in cubic centimeters}} \times 100$$

From these measurements it was possible to calculate or report slaking time; water of plasticity; plasticity; air shrinkage (volume shrinkage was obtained directly from measurements and linear shrinkage was calculated from volume shrinkage; only linear shrinkage is reported); tensile strength; effect of rapid drying; probable injury from auger structure; behavior at several temperatures, including fire shrinkage (volume and linear; only linear is reported), color, hardness, per cent of absorption and porosity, and special characteristics, such as checking and black coring; and range or rate of vitrification.

Refractory clays were made into smaller bricklets and burned in a Meeker (compressed-air) muffle furnace.

The large number of gray-drift clays that are rendered useless by limestone pebbles made necessary a modification in treatment. The Minnesota plant which is most successful in removing these pebbles operates at Hutchinson on material containing 70 per cent of grains fine enough to call clay and 30 per cent sand. About 9 per cent of the mixture is lime. It was thought that a determination of these ratios in other deposits would be of more value than an attempt to burn brick from the pebbly clay. In conformity with the practice at Hutchinson, very little material coarser than 20-mesh was used. The sand was separated and caught on a 100-mesh sieve.

The few analyses made are of value in estimating the availability of fire clays and in comparing the clays of different formations. Two sets of vitrified brick were subjected to a rattler test by Edward Orton, jr., at Columbus, Ohio.

The kaolin burned white and was glazed to ascertain whether the color was satisfactory.

Several mechanical analyses were made by the use of a centrifuge, according to the methods of the United States Bureau of Soils.[1] In most mechanical analyses it is common to class all particles smaller than 0.005 millimeter as "clay." In the analysis of soils this is one of several fractions resulting from the analysis, each of which is of about equal importance; but in clays these fine particles are uniformly abundant and it is advantageous to make a special classification of the finest material. Coarse sizes are not abundant in clays and may well be thrown together as coarse sand. The following groups were therefore adopted in this work, and the results were checked by microscopic measurements:

Mechanical classification of grains in clay.

	Diameter in millimeters.
Fine clay	Less than 0. 001
Coarse clay	0. 001– . 005
Silt	. 005– . 05
Fine sand	. 05– . 5
Coarse sand	Larger than . 5

The samples were air dried before and after separation, and the total of the fractions was usually 96 to 100.7 per cent of the sample used to start with. The analyses were recalculated to 100 per cent.

The quality of products was tested in the engineering department of the University of Minnesota, and other available records were added.

RELATION OF TESTS TO PRACTICE.

As an example of the relation of tests to practice, comparison may be made of the clays of Coon Creek, West St. Paul, Red Wing, and Wrenshall, all of which have been largely used. All the clays slake promptly and develop fair plasticity. That from West St. Paul is the most plastic and is found to work somewhat stiff. Each has a tensile strength of more than 100 pounds to the square inch, which is usually considered necessary for ceramic work. The sandy red drift of Coon Creek shows the smallest shrinkage in drying (5 per cent), but none of the clays show more than 8 per cent, which is small enough to insure against danger of serious warping or cracking. Rapidly dried briquets made from these clays were just as strong and free from checks as those slowly dried.

[1] U. S. Dept. Agr. Bur. Soils Bull. 84, Washington, 1912.

In firing, these clays are typical of the groups to which they belong. Under vitrification (see fig. 8, p. 84), Pleistocene clays, like the laminated clay of Wrenshall and the red drift of Coon Creek, show a sudden drop in porosity, and the older shales, Cretaceous and Decorah, a much more gradual decrease. This rate of decrease and the relation of low porosity to the viscous state largely determine the uses of the clay. The university tests show that the clay of Wrenshall can not be burned to a very low porosity without danger of melting out of shape. The clay of Coon Creek shows unusual resistance to fire for a few degrees after a somewhat sudden drop in porosity. The shales of West St. Paul and Red Wing both show a very gradual falling off in porosity as the heat is increased and, though not tested in the university laboratory to a porosity below 5 per cent, they can easily be burned to a product of that density without danger of melting. The two shales differ most remarkably in the temperature at which the lowest porosity is reached, that from West St. Paul being well burned at about 2,150° F., and that from Red Wing requiring 2,700° F. The shale of West St. Paul contains so much organic matter and ferruginous fluxes that black cores and vesicular texture are likely to develop unless it is slowly and carefully burned. The color of the product is indicated very definitely for each clay.

These results would be sufficient to warrant very definite conclusions as to the uses of the clays, which are now being used for the purposes for which they are best suited. The clay of Wrenshall will produce a porous but good common brick. The clay of Coon Creek will yield a much harder, denser brick, suitable for harder usage, as in foundations, public buildings, and even pavements. The clay of Red Wing is of still higher grade and will make light-colored vitrified ware like stoneware, as well as light-colored paving brick. It is used only for stoneware, and the more ferruginous varieties for sewer pipe. A shale that vitrifies at so low a temperature as that from West St. Paul is usually believed to give a product that even if well burned will not have the resistance to abrasion required of a street pavement nor the strength needed for sewer pipe. The shale of West St. Paul, however, is eminently fitted for high-grade brick and tile.

TECHNOLOGY OF CLAY.

By E. K. Soper.

PROSPECTING.

USUAL METHOD OF PROSPECTING.

Most of the developed deposits of clay have been found by men occupied in other pursuits, who had the requisite knowledge and skill to observe the signs about them and to investigate what others would pass by unheeding. One who has become familiar with the appearance of a clay will recognize similar material elsewhere.

There is not a farm in Minnesota that does not contain some clay, good, bad, or indifferent, in deposits of greater or lesser extent. Common brick clays are so widely distributed that it is unwise to prospect for them in places far from lines of transportation, except for local trade. In many places, however, a little prospecting for material to supply such local trade with better brick than are now made would be worth while. A plowed field, an excavation along a road, a well, a posthole, or the bank of a stream may reveal clays of a type known to be of value. The 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 the necessary excavations. Some clays do not lie so near the surface and are not so easily discovered. Yet, if they are fire clays or kaolins, they may be worth some effort at prospecting and development.

STRATIGRAPHIC PROSPECTING.

The stratigraphic method of searching for clays proceeds on an assumption that is fairly reliable, if used with caution. Where sedimentary formations lie in nearly horizontal layers, as in the southern half of Minnesota, it may often be assumed that they are continuous underground, even if concealed by soil and vegetation. For instance, the rock formations of southeastern Minnesota are well exposed at many places in bluffs, at the top of which is a limestone containing fossils that prove it to be the Galena. Below this limestone come, in order, the Decorah shale, the Platteville limestone, and the St. Peter sandstone, each with a definite thickness and character. If near Faribault, for example, there should be found a number of such exposures of uniform character, and if at a particular place no formation except the Galena crops out, it is safe to conclude that under the surface at that place the Decorah shale lies at the same elevation as it does in other parts of the area. Such an assumption is useful in finding some clays.

A line of springs along a hillside also often gives evidence of clays underground. Rarely, when conditions seem to warrant it, drill holes and shafts are sunk to considerable depths in search of clays.

ECONOMIC CONSIDERATIONS.

Common clays are so widely distributed in Minnesota and in most other States that the choice of a deposit to exploit 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 Minnesota are destined to remain untouched for years because they are too inaccessible. At present it will not pay to haul fire clay or pottery clay by wagon to any distant railroad point for shipping. The price in 1915 for good fire clay was about $1.50 a ton, and the cost of a wagon haul would absorb most of the profit at that price. The cost of labor, fuel, and other material should also be considered. A few high-grade clays may sell for enough to overcome the handicap of unfavorable market conditions.

After studying market conditions and finding a clay, one should determine before a plant is erected, first, the amount of clay; second, its general character; third, the conditions of working, including accessibility of all materials needed in the working; and finally, if all these are favorable, the exact and detailed character of the clay. Each of these items deserves the most careful attention.

CLAY PLANTS.

LOCATION.

If a clay deposit is extensive, like the glacial clays in Minnesota, the success of a plant may depend on the location selected. The relation to transportation facilities is most important. No matter how fine its quality, the clay is worthless if it is inaccessible, and for this reason prospecting in regions remote from transportation facilities is useless. It is also necessary to consider the overburden with regard to stripping operations. Another essential consideration is the drainage, provision for which is in many places difficult and in some flat regions can be made only by pumping. The possibility of mixing different clays controls the location of many plants, though foreign material whose admixture will improve the grade of the product can often be profitably brought from a considerable distance. Some sand also must usually be available for mixing with the fat clays used for common brick. Most high-grade clay products, such as chinaware, stoneware, and terra cotta, are made from mixtures rather than from run of bank material.

The exact location of the buildings and yards with respect to the clay pit is a matter that deserves more attention than it usually receives. In numerous places yards and buildings have been placed over the best clay in the deposit and must be moved before the clay is excavated. The plant should be arranged so that the material may progress from pit to machine, to drying racks, to kiln, and to shipping point in regular sequence, without any great distance between points and without retracing its route. (See fig. 5.)

MINING THE CLAY.

Open pits are most commonly used for obtaining the clay, underground work being too expensive except for kaolins and fire clays. The expense of mining underground is affected by the size of the bed, the drainage, the roof, and the depth. In Minnesota the high-grade clays are well situated except that the roof consists of shale or drift and is not strong.

Pick and shovel are used on most clays, and the best parts of variable high-grade clays may be carefully selected. Uniform clays

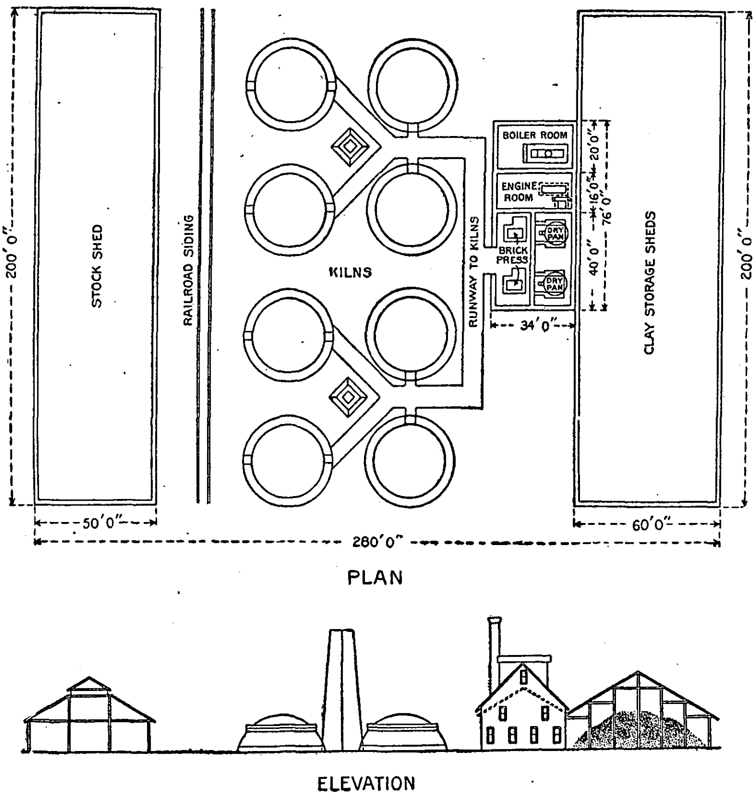


FIGURE 5.—General arrangement of brick plant.

requiring no selection in the pit may be excavated with a plow and scraper or with a steam shovel, which in large plants is the most economical. (See Pl. XIII, *A*.) Blasting is not usually necessary. Any overburden is removed by similar methods. Where land is valuable for farming and the pits are shallow, as in the Red River valley, the soil of the overburden is spread on the bottom of the worked-out pit.

Drainage is an item of expense in some places. Ditches are most economical if an outlet can be found, but in many places pumping is necessary.

Deep pits are worked in benches, though in a deposit of firm shale where proper protection can be provided, as at West St. Paul, high vertical faces are worked by undermining and caving. In some other States, where high-grade clays occur in peculiar forms, special methods of mining have been adopted. The southern kaolin deposits, for example, are worked by a series of circular or square pits.

TRANSPORTATION FROM PIT TO PLANT.

Where the plant and the clay bank are close together excavation and transportation are combined by the use of scrapers and similar apparatus. Horse carts and cable-dump cars are very commonly used. In some of the larger deposits in hilly ground aerial tramways and even chain conveyors are used. Where the clay lies along a navigable stream or lake, like many deposits in Minnesota and Wisconsin, barges can be used both for transporting the raw material to the factory and for shipping the finished product. There are but few plants in Minnesota where the raw clay has to be hauled far. At present it will not pay to haul even good fire clay or pottery clay by wagon to a distant railway shipping point. The only Minnesota clays extensively shipped any great distance are the Cretaceous clays of Goodhue County. The raw material from these deposits is loaded on flat cars and hauled to Red Wing, a distance of 12 to 18 miles. Another part of the product is shipped to Hopkins for the Minneapolis sewer-pipe plant. Some high-grade clays may prove sufficiently valuable to warrant transportation for a considerable distance.

DRAINAGE.

Pits in clay deposits that underlie flat areas are usually drained by pumping, especially if they are deep. Many thin clay deposits can be drained by a proper system of trenches. Too little attention is given to drainage at many clay plants. Where the deposits are on steep hillsides improper drainage may cause caving.

PREPARATION OF THE CLAY.

PRELIMINARY TREATMENT.

Some clays, after being dug and brought from the pit to the yards, require preliminary preparation before they are ready for the molding machines. Many clays are rendered more plastic after weathering, and in a few localities where greater plasticity is desired the material as it comes from the pit is spread out in the sun for several weeks or months. Other clays are mixed with sand or some different clay. Very few yards use the best clay alone; as a rule more or less sand is mixed with it, especially for making ordinary brick and tile. The most common practice is to take the run of bank material, including a foot or two of sandy-surface soil. The sand increases the density of limy clays and decreases the air shrinkage and sometimes the fire shrinkage.

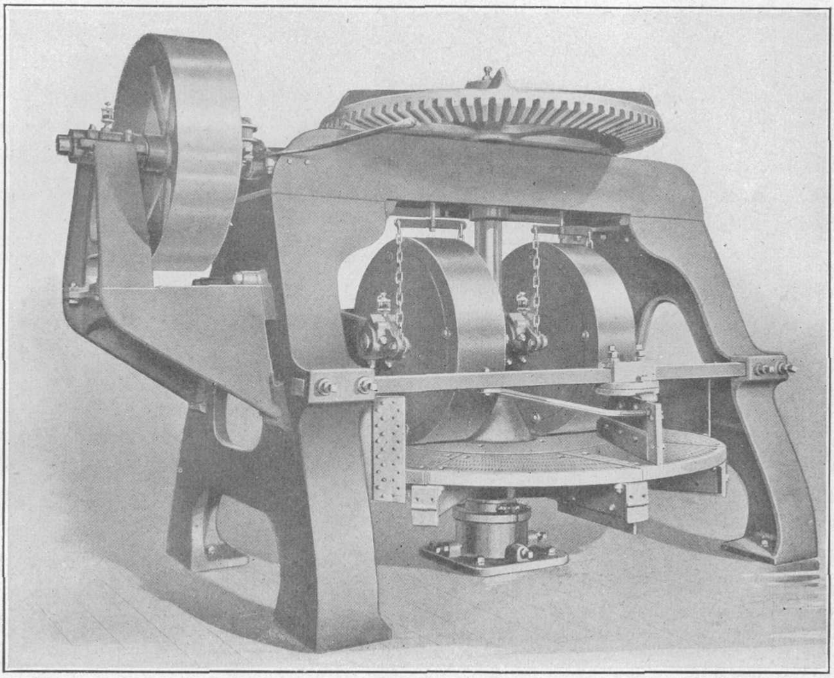
If the clay contains sticks or large pebbles or concretions they are sometimes picked out by hand. Hard clays and shales must be crushed, and if the clay contains the top layer of soil it may include some pebbles, which must be either crushed or removed. For some shales fine crushing is absolutely necessary to obtain plasticity.

GRINDING.

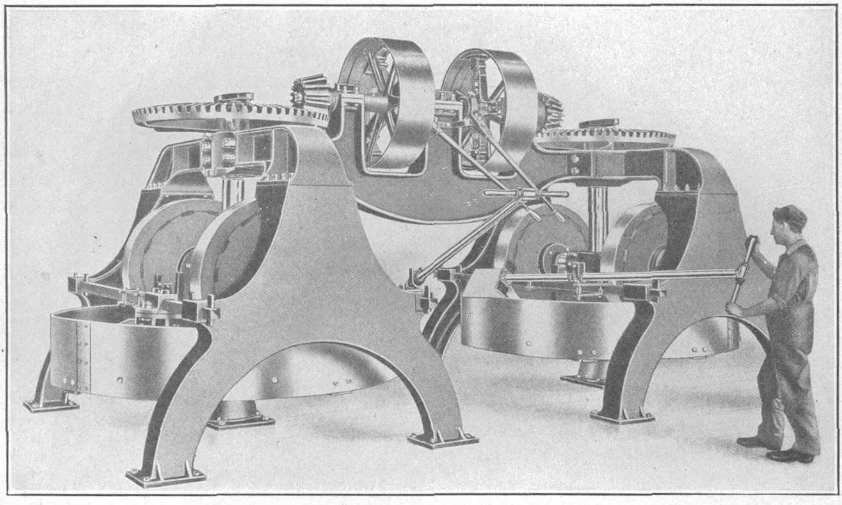
The commonest types of crushing and grinding machinery are dry pans, jaw crushers, disintegrators, and rolls. Ball mills are sometimes used for very fine wet grinding. Clays of ordinary hardness and toughness do not require crushers or rolls and can be worked up directly in wet or dry pans. Rolls are used more than jaw crushers because of the tendency of the clay to pack and clog the crusher. The commonest combination used in Minnesota consists of rolls and pug mills. The dry pan is a heavy pan supported and driven by a vertical shaft. Within the pan are two or more heavy mullers or wheels supported on a horizontal shaft. As the pan revolves, the mullers are rotated in the opposite direction by their contact with the pan, grinding the lumps of clay. (See Pl. III, *A*.) Several types of disintegrators are on the market, but the commonest break up the clay by impact against the bars of opposite revolving cages or by the impact of flying hammers attached to axles revolving in opposite directions. As the axles revolve the hammers are flung out by centrifugal force and beat the clay to pieces.

WASHING.

Many higher-grade clays, such as kaolin and stoneware clays, are washed after disintegration to remove sand and other impurities of a harmful nature. The disintegrated clay is mixed with water to a thin sludge and settled in a series of shallow tanks. The sand settles out rapidly in the first two tanks and the finer clay substance is kept in suspension longer and is recovered in the lower vats. This wet clay (slip) then passes through filter presses to remove the remaining water, and the resulting cakes are tempered or are dried for shipment. The details of the process now applied at Red Wing are described in the Goodhue County report (pp. 165–173).



A. DRY PAN.



B. DOUBLE 8-FOOT WET PAN.

SOFT-MUD BRICK MACHINE FORMERLY USED AT JACKSON.

SCREENING.

After grinding or washing it is usually necessary to use a screen to separate coarse or uncrushed material from that ready for molding. Dry pans combine the grinding and screening by means of perforations in the bottom of the pan.

OVERCOMING THE TROUBLE FROM LIMESTONE PEBBLES.

METHODS.

Many poorer-grade clays for brick and tile are not washed, because the value of the product will not offset the extra expense. However, the gray drift that is so widespread over Minnesota must be cleaned before it can be used for the manufacture of high-grade ware. Limestone pebbles are its chief defects, for after the clay is burned they will slake, swell, and destroy the brick. They can be removed or rendered harmless in several ways. If they are not too abundant, fine grinding may be sufficient. Fairly fine grinding and immersion in water after removal from the kiln will render the lime harmless. The addition of some salt with the water used in tempering the clay seems to prevent the swelling and slaking of the lime. By drying and gently grinding, so that the clay is disintegrated and the harder pebbles left, it is possible to catch most of the lime on a screen. The use of certain machines[1] will remove pebbles from plastic clay. Washing, however, is the most effective process and has been commercially successful in a plant that uses material such as can be found in nearly every part of the State. This plant is described below.

HUTCHINSON PROCESS.

At Hutchinson, in McLeod County, the gray drift is cleansed of limestone pebbles by a process that is probably not duplicated in America. The washing machinery occupies 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, where it is mixed with an excess of water and agitated by a series of vertical rods fastened to a rotating crossbeam. The harrow-like motion of these rods tends to throw the larger pebbles toward the center and leaves the fine clay and sand suspended and distributed throughout the washer pit. A bucket elevator of continuous operation dips into the pit near the center and removes the gravel. The gravel, if cleansed, forms a by-product of considerable value. At the sides of the pit a screen of proper mesh allows the escape of the fine sand and

[1] The Diesner clay cleanser: Brick, vol. 31, No. 5, 1907.

clay to one of a series of open ponds in which they are allowed to settle. After a time some of the water is 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. After partial drying the material is 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. Experiments are in progress to determine whether the clay is improved by standing in the settling ponds all winter. The gravel is sold for concrete. Both the clay and the sand contain a considerable amount of calcium carbonate (see analyses in report on McLeod County, pp. 191–193), but if care is taken to remove the coarser sand the lime does no harm, and it is certainly less abundant than in the unwashed drift. The plant at Hutchinson uses three round downdraft kilns, and plans are made to double the capacity. It has been found possible with this clay to produce a very good draintile and hollow building block, so that the production of common brick has become secondary. Recently most of the tile made from clay have been of small sizes; the gravel by-product was used with cement for larger tile. M. C. Madsen, of Hutchinson, has been developing this process for about 20 years.

A large plant of this character, shipping its product over a considerable territory, would meet the competition of plants using clay that is free from limestone pebbles and that is therefore more cheaply worked. A local plant of medium size, however, could succeed, and there is room for several such plants in the western and northern parts of the State.

GRINDING AND SCREENING.

If the clay is not too heavily charged with limestone pebbles, it is possible that a method cheaper than washing may be applied. According to Binns and Coates:[1]

> Lime grains as large as would be rejected by a 12-mesh sieve are objectionable even in small quantities, for though the brick may not be ruptured there is apt to be an unsightly spalling of the surface. To be entirely safe, lime grains must be ground to pass a 36-mesh sieve. Lime as fine as this may be present in a proportion as high as 12 per cent. The danger of rupture from lime grains may be almost completely avoided by a saturation of the brick on being drawn from the kiln.

SATURATION OF THE BURNED BRICKS.

Saturation of the freshly burned and cooled brick is especially effective if the brick are very porous. Clays that burn to a very dense body would probably be more affected by the lime content than those making soft, porous building brick. This treatment has been

[1] Binns, C. F., and Coates, M. A., Am. Ceramic Soc. Trans., vol. 14, p. 22, 1912.

tried at several places on the gray drift and, though partly successful, has not yielded so high grade a product as that obtained by the washing.

COLORING.

Special colors are most commonly obtained by adding compounds of manganese or of iron. At Preston the red color of the brick is improved by the use of "mortar-color" red in the molding sand. A similar process is reported from Menomonie, Wis., and Winona, Minn., and may give satisfactory results elsewhere in Minnesota. At other places a glaze or slip is used to impart the desired color. A salt glaze is common, especially on sewer pipe. Pottery, stoneware, and fancy face brick may be covered with a thin layer of some slip clay that is known to burn to the desired color. Where a slip is used special care must be taken that the difference in shrinkage between the slip and the body of the ware is not too great, for uneven shrinkage may cause the slip to peel or crack.

MIXING.

Many of the best plants in the United States mix clays from two sources. Very little of such mixing is done in Minnesota, though tests show that it would much improve some of the products, especially those made from slate and red clay near Duluth. Careful mixing is practiced at West St. Paul, where the upper and lower parts of the Decorah shale are unlike. At most clay banks, however, mixing is effected merely by running the scraper from the top to the bottom of the bank.

PREHEATING.

Some defective clays may be greatly improved by preliminary heating to 200° to 300° C. (see p. 34), particularly joint clays, which are too plastic to work easily and which crack badly on drying. The process will probably be used in certain parts of Minnesota, where the only clays available are joint clays. The expense is not great, but in most places clays that do not require such treatment are available.

TEMPERING.

Before the clay is molded it must be thoroughly mixed with water until it attains the required degree of plasticity. This process, which is called tempering, may be carried out in the soak pit, the ring pit, the wet pan, or the pug mill.

SOAK PIT.

The soak pit is a square or circular pit in which the clay is mixed by hand or by horsepower. As a rule the sides of the pit are of natural earth, unboarded, though planks or stones may be placed on the bottom. The clay is dumped in, usually without any preliminary crushing, and is mixed with water. Many pits have a vertical post in the center with a rod so attached that a horse may rotate it and thereby mix the clay. The soak-pit method is applicable only to the soft-mud process. (See p. 59.)

RING PIT.

The ring pit is similar to the soak pit, except that it is invariably circular, has permanent walls, and has a post in the center, to which is attached a long horizontal rod which carries a wheel. As the horizontal rod is revolved about the vertical post the wheel travels back and forth along the rod, from the center to the outside of the pit and back again, thoroughly mixing the clay and water. The ordinary ring pit has a capacity of 3,000 to 8,000 brick a day.

WET PAN.

The wet pan is similar to the dry pan (see p. 54), except that it has a solid instead of a perforated bottom and can ordinarily be emptied only when it is stopped. Some lumps of clay, therefore, always remain in the bottom. Its chief advantage is that it grinds and mixes at one operation. (See Pl. III, *B*.) It is used in making sewer pipe, fire brick, and paving brick.

PUG MILL.

The most common method of tempering in use at the larger plants is that employing the pug mill. This mill consists of a cylindrical trough in which revolves a shaft carrying arms or knives set at an angle. The clay, with water in proper amount, is fed into the upper end of the mill and is forced by the revolving arms toward the lower end. On the way it is thoroughly mixed, all lumps are broken down, and the whole is kneaded into a plastic mass. The method and rate of feeding the clay to the mill will differ at different plants but are usually controlled by some mechanical device. Pug mills are made in different lengths, and as the thoroughness with which the clay is mixed depends chiefly on the length of the trough, the machine must not be too short for the clay to be used. Many machines are not long enough and do poor mixing, and poor mixing invariably results in a poor grade of brick. When the pug mill is used in conjunction with the stiff-mud method of molding (p. 60), a special combination of pug mill and auger machine is usually employed, by which the clay, after being mixed by the revolving arms, is forced out at the lower end through a die in the shape of a long bar or ribbon.

In Minnesota numerous pug mills and combination pug and auger machines are used. At the smaller plants ring pits are nearly always employed. At some brickyards, as the result of improper mixing, many lumps of clay half an inch or less in diameter are allowed to get into the brick without being crushed. This is undesirable and causes the splitting or breaking of the brick.

WEDGING.

In many pottery plants the washed clay, after it comes from the pug mills, is given an additional tempering by kneading by hand or in rolls. This treatment is called wedging.

MOLDING.

BRICK MOLDING.

There are three methods of molding brick—the soft-mud process, the stiff-mud process, and the dry-press process.

SOFT-MUD PROCESS.

Bricks may be manufactured by the soft-mud process either by hand labor or machine. Hand-molded brick made in this manner are known as slop brick and are now made only at the small yards. The molds, which contain compartments for six brick, are first wet and sanded. Into these the molder flings the wet clay from the soak pit with some force, so as to fill all the corners. The tops are cut off by a wire stretched between two-sticks, and the brick are taken to the drying floor, which is usually only a level place in the yard, and are turned out of the mold on a sanded surface. When part dried they are turned on edge. A good molder can turn out several thousand bricks a day by this method.

For machine-molded soft-mud brick the clay is put into a pug mill that pushes it into a hopper from which it is forced by a plunger into molds beneath. These molds have been sanded by hand or by a special mechanical device. As the plunger is withdrawn the hopper is again filled with clay from the pug mill. The filled mold is removed by a lever-operated mechanism and an empty mold put in its place. (See Pl. IV.) Brick molded by the soft-mud process have fine sanded surfaces. The machines have a capacity of 8,000 to 15,000 brick a day when driven by horsepower. and 20.000 to 35,000 when driven by electric or steam power. The soft-mud process is adapted to clays of low or medium plasticity and is the one most commonly used.

STIFF-MUD PROCESS.

Stiff-mud molding is almost never done by hand. Clays of moderate plasticity are mixed with considerably less water than is used in the soft-mud process to a sufficient stiffness for the wet ware to be handled without danger of deforming it. There are two types of stiff-mud machine—plunger and auger. The plunger machines are essentially the same as those employed in the soft-mud process, but their use has been rapidly diminishing and is now restricted to the manufacture of sewer pipe. Practically all stiff-mud brick are now made by the auger machine, which consists essentially of a pug

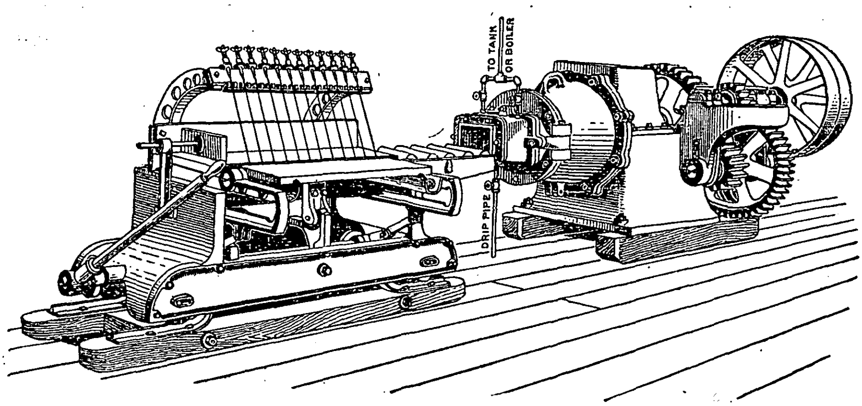
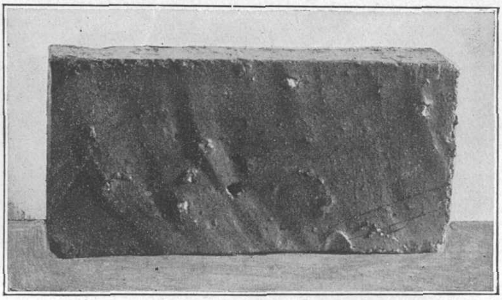
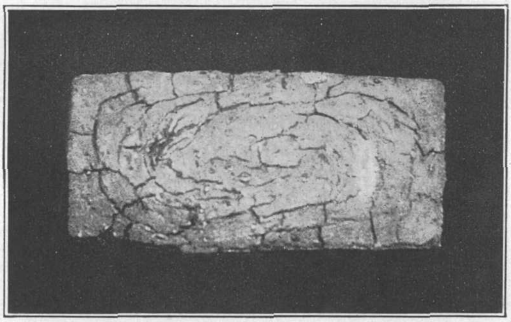


FIGURE 6.—Auger machine and wire cutter. Sketch from catalogue of American Machinery Co.

mill, in which an auger is placed at the end of the shaft. After the clay and water are mixed by the blades on the revolving shaft the plastic mass is taken up by the auger and forced from the lower end of the machine through a die, in the form of a continuous ribbon or bar of clay. By changing the die, common brick, cylindrical drain-tile, hollow building blocks, fireproofing, and other shapes can be made in the same machine. As the ribbon of clay comes through the die it passes on a traveling belt to a cutter, which may be operated automatically or by hand. Nearly all stiff-mud brick are now cut automatically, by wires placed on a revolving wheel or on a bar operated by a lever. (See fig. 6.) The brick may be side cut or end cut, and they have smoother surfaces than the sand-molded brick. Any pebbles in the clay may cause difficulty in the cutting, though usually the difficulty is not serious. (See Pl. V, *A*.) Auger machines tend to produce a laminated structure in some clay, which weak-

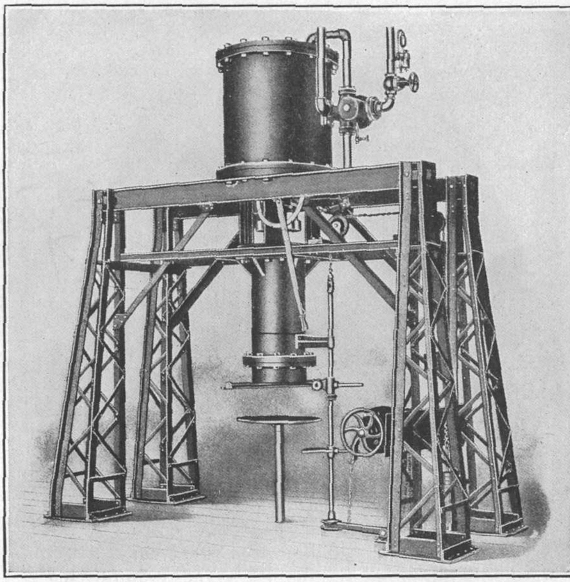


A. WIRE-CUT BRICK MADE FROM PEBBLY CLAY.

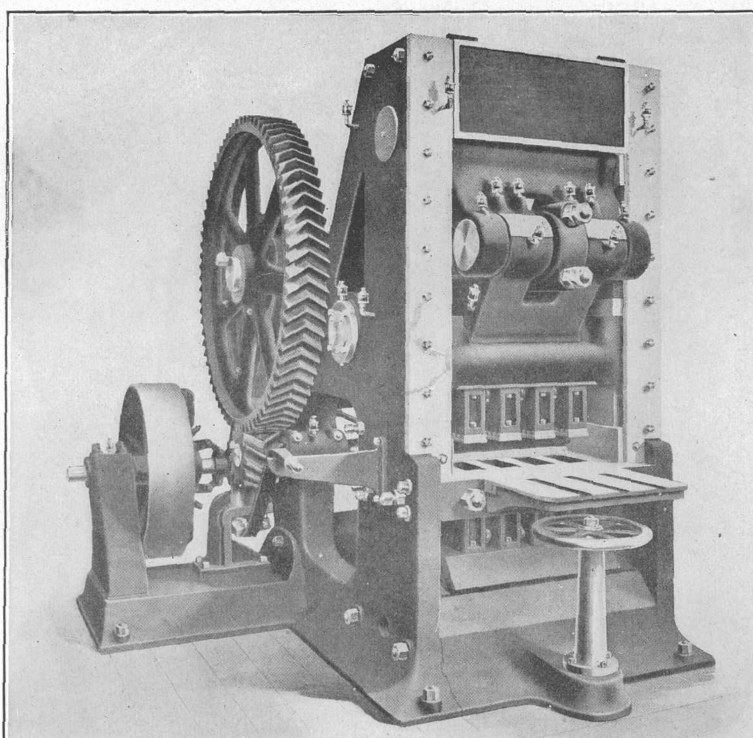


B. AUGER STRUCTURE IN AN OVERBURNED BRICK.

C. BRICK DRYING IN OPEN SHEDS.



A. SEWER-PIPE PRESS.



B. FOUR-MOLD DRY PRESS BRICK MACHINE.

ens the brick and renders them practically worthless. (See Pl. V, *B*.) Unless the dies are well lubricated the soft clay may stick to the corners and tear, producing rough, ragged edges. Generalization as to the behavior of any type of clay is not possible.[1] The form of the die can usually be adjusted to remove the worst trouble. The only other factor capable of control is the tempering, and this requires personal and careful attention. By proper adjustment the process can be made to roughen all sides of a brick and produce an imitation of the popular "klinker" brick. The capacity of a stiff-mud auger machine ranges from 45,000 to 60,000 brick in 10 hours. In some machines double or triple dies are used and the output is correspondingly increased.

RE-PRESSING.

It is often desirable to re-press brick that have been molded wet. Soft-mud brick are likely to be somewhat irregular in size and to come from the machine with comparatively rough edges. Re-pressing improves the shape, increases the density, and makes better face or front brick. Stiff-mud brick are also sometimes re-pressed in order to remedy the laminated structure produced by the stiff-mud auger machines (p. 60), which considerably lessens the tensile and crushing strength. The additional pressure, however, does not always obliterate the lamination. In general, where different shape is desired, where rounded corners or smoother surfaces are wanted, or where there is a tendency toward lamination re-pressing is beneficial. The re-pressing is done in a plunger machine. The brick are placed in the molds automatically and are pressed to any desired shape for which a mold can be made. This process is used in making complex forms such as interlocking roofing tile.

DRY-PRESS PROCESS.

The dry-press process is so named from the fact that the ground clay is molded into brick in its natural dry state without being mixed with water to a plastic mass. It is not, however, strictly a dry method, for there is usually 5 to 15 per cent of water in the clay as it comes from the dry pan. The process is best adapted for the production of fancy and front brick, but at many of the larger plants common brick are now molded by this method. The clay should be ground to pass a 16-mesh screen. The dry-press machines are of the plunger type and the clay is fed from the charger into the molds. The plungers descend upon the powdered clay, and at the same time

[1] Artz, W. H., Flow of plastic clay through dies: Am. Ceramic Soc. Trans., vol. 11, p. 411, 1909.

the bottoms of the molds are forced upward, so that the brick are subjected to pressure from both sides. The pressure is considerably greater than is applied in any other process. The bottom of the mold continues to move upward after the upper mold is withdrawn, so that the brick is forced up and out onto the dry table. (See Pl. VI, *B*.) The molds are heated by steam to prevent the clay from sticking to them. As the air contained in the ground clay is compressed and imprisoned in the brick and, unless given an opportunity to escape, would expand and spoil the brick on the release of pressure, the faces of the molds are provided with minute air holes. This precaution is not necessary in any of the other processes. Brick molded by the dry-press process are ready for the kilns directly after molding and do not need to be subjected to preliminary drying. The advantage of dry pressing is chiefly that smooth brick with sharp, true edges are produced by a single molding process. Two, four, and six mold machines are on the market. The capacity of the six-mold machine is about the same as that of the soft-mud machine.

HOLLOW WARE AND TILE.

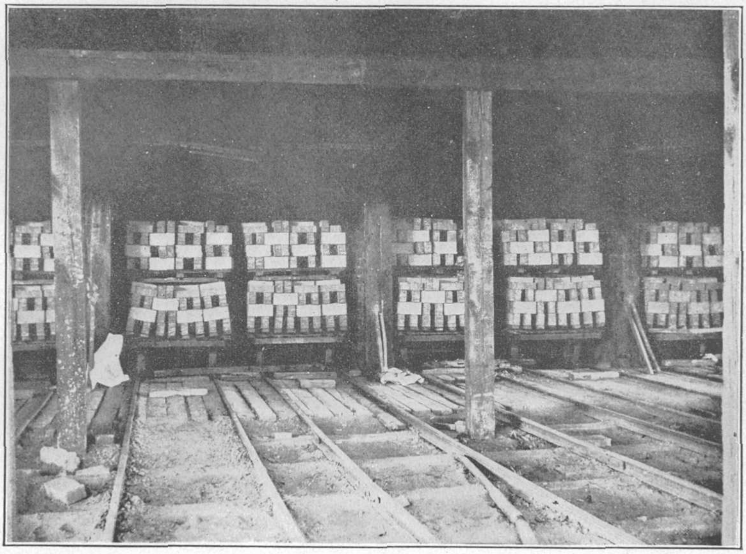
Draintile, hollow brick, hollow tile, fireproofing, and terra cotta are molded by a stiff-mud process not essentially different from that employed for molding stiff-mud brick. Products of almost any shape can be made by the stiff-mud method by changing the form of the dies, but different clays are necessary for the different kinds of ware. Almost any good plastic clay that has a moderately high tensile strength and not too much shrinkage and that would make a good common brick can be used for cylindrical draintile.

SEWER PIPE.

Sewer pipe are molded in stiff-mud machines of the plunger type. The essential parts of the machine are two cylinders connected by a piston—an upper steam cylinder and a lower cylinder into which the clay is fed. As the steam enters the upper cylinder, the piston is forced down on to the clay and presses it through a die at the bottom. At the end of the stroke the pipe thus molded is cut and the piston is raised to allow more clay to enter. (See Pl. VI, *A*.) Elbows, turns, and combined shapes are molded in plaster casts, each half of the pipe being molded separately, and the two being cemented by slip clay. As the clay dries the air shrinkage loosens the pipe in the mold and permits its removal.

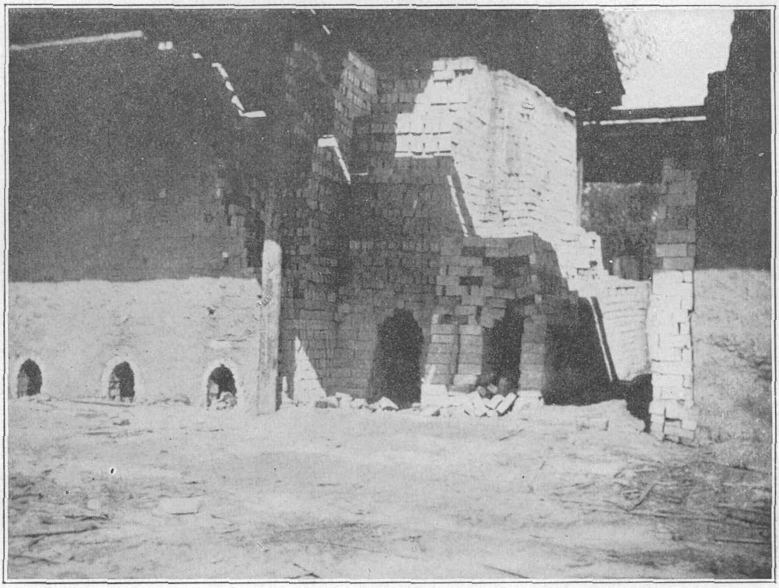
POTTERY.

The processes used in the manufacture of pottery and chinaware are so complex and require so much specialized skill that detailed

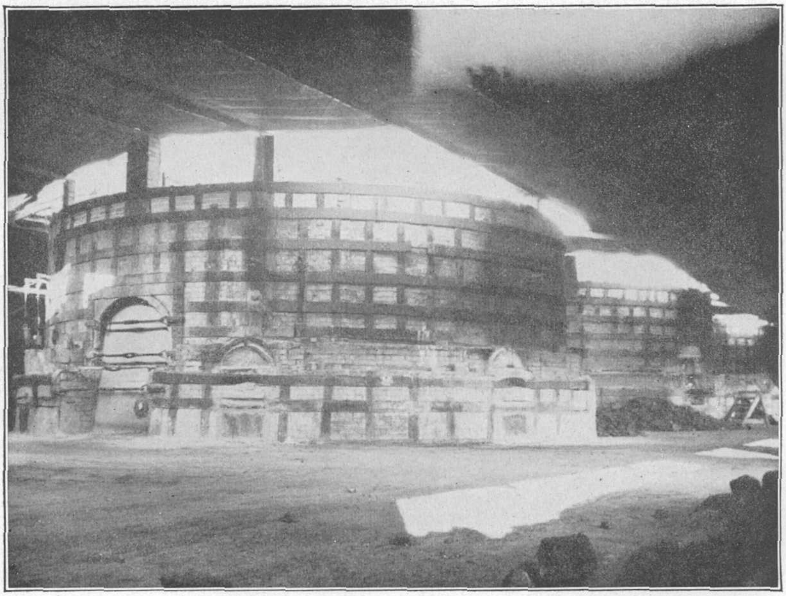


A. BRICK DRYING ON CARS IN TUNNELS.

B. HOLLOW WARE DRYING ON A FLOOR.



A. SCOVE KILN, SHOWING HOW BRICK ARE PILED.



B. ROUND DOWNDRAFT KILN AT HOPKINS.

discussion is not warranted in a report of this nature. Certain shapes are hand molded, but machine molding on wheels is most common. Round ware is generally molded by jolly wheels and lathes. Some forms are pressed or poured into plaster molds. All pottery is dried in rooms where the moisture and temperature are carefully controlled.

GLAZING.

Little cheap earthenware is glazed, but the higher grades of stoneware are either slip or salt glazed.[1]

DRYING.

METHODS.

All brick and other ceramic products except those molded by the dry-press method have to be dried before burning in order to free them from the excess of water of tempering. If the clay shrinks greatly or if the products are complex in form, the process requires great care. It may even be necessary to place the wares first in a room in which the air is not very dry, and it is often best not to apply heat until drying is well advanced. Drying may be effected in open yards, sheds, and pallets, or drying floors and tunnels.

Bricks are commonly dried in pallet dryers—long, low, narrow sheds with open sides and movable roofs. The wet brick from the molding machine are placed on small boards called pallets, which hold about six bricks each, and are carried on trucks or on a traveling belt along alleys between the drying sheds, where they are placed on shelves in the open air. (See Pl. V, *C*.) In the smaller yards and at most soft-mud brick plants the brick are placed on ground that has been smoothed off and are allowed to dry in the sun with only boards ("hacks") to protect them against rain.

Drying floors are similar to open-yard dryers, except that they are permanent and that at some plants they are partly covered by a roof. (See Pl. VII, *B*.)

Drying tunnels are cylinders or tunnels artificially heated to about 120° C. by the waste heat from the kilns or the power plant. The wet brick from the molds are loaded on cars, which are run through these tunnels very slowly (see Pl. VII, *A*), remaining in them for a length of time that depends on the amount of moisture in the clay, the quality of the clay, and the behavior of the clay on rapid drying.

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[1] For a detailed description of the manufacture of pottery and other ceramic products see Ries, Heinrich, Clays, their occurrence, uses, and properties, 1906.

EFFLORESCENCE.

Brick made from some clays become covered during the process of drying by an efflorescence, the water in the clay dissolving out soluble salts and depositing them on the surface of the brick as it evaporates. Calcium sulphate is the most common salt thus formed; others are sulphates of magnesium, potassium, sodium, iron, and aluminum. Occasionally carbonates and rarely silicates are formed in this way. Efflorescence during the drying process can be prevented by leaching the clay to dissolve out the soluble salts, by adding barium salts, by using pure water in tempering the clay, or by careful drying. A simple test to determine the approximate quantity of soluble salts in the clay will often indicate which process would be best to use.[1]

BURNING THE CLAY.

KILNS.

The numerous types of kilns in use have been described and classified by Beyer and Williams.[2]

UPDRAFT KILNS.

The most common type of kiln is the temporary updraft scove kiln (Pl. VIII, *A*), which is used at nearly all the smaller brickyards. The bricks are built up into a rectangular open-work mass, under which are left a series of parallel arches running through the pile and spaced about 2 feet apart. After the pile is built up it is surrounded by a closely built two-brick course wall, daubed over with wet clay. It may be covered with a board roof supported on a frame outside the kiln. The kilns are only temporary and must be rebuilt for each new batch of brick. They are used only for common brick and can not be heated to high temperatures. Their use necessarily involves a high percentage of loss around the arches from overburned brick and probably another serious loss around the outer wall from underburned brick.

Another type of updraft kiln is the permanent scove kiln, which is similar in principle to the temporary scove kiln except that it has permanent walls on two or three sides but no roof.

Pottery may be burned in updraft kilns that have compartments, chambers, muffles, or saggers to keep the ware from direct contact with the flames.

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[1] Jour. Ind. and Eng. Chemistry, vol. 2, p. 373, 1910.

[2] Beyer, S. W., and Williams, I. A., Technology of clays: Iowa Geol. Survey Ann. Rept., vol. 14, p. 288, 1904. See also Snyder, L. C., Clays and clay industries of Oklahoma: Oklahoma Geol. Survey Bull. 7, p. 81, 1911.

DOWNDRAFT KILNS.

Downdraft kilns may be either round (Pl. VIII, *B*) or rectangular and are provided with permanent fire boxes along the outer walls. The hot gases pass through flues to the top of the kilns, down through the spaces between the clay ware, out from the bottom of the kilns through the flues, and upward through the stack. Downdraft kilns have distinct advantages over those of the updraft type, although they cost considerably more. Their temperature can be more exactly controlled and can be raised higher, and they waste less in overburned and underburned products. In the updraft kiln, if the lower brick become overheated, the entire mass may melt and sink down, a danger that is obviated in the downdraft kiln.

CONTINUOUS KILNS.

A continuous kiln consists of several chambers connected with one another and with a central stack. The heated gases pass from one chamber to another and finally out the stack, the waste heat from one chamber being utilized in preheating the next. In a properly operated continuous kiln the clay ware in some of the chambers is being cooled; in others it is being burned at maximum temperature; and in still others it is just being placed in position all at the same time. The continuous-kiln system is especially adapted to larger plants; and, though it is chiefly used for products of the better grade, it is employed in many plants for burning common brick. The first cost of the continuous-kiln system is greater than that of other kilns, but many advantages are claimed by the manufacturers, as follows: Saving of fuel (only one-third of the fuel is required); better, more uniform burning, and consequently a more uniform color; fewer seconds and culls; less labor for firing; longer life; less cost for maintenance and repairs; no smoke; less ground space for a given daily capacity; less handling of fine ware; superior arrangement for water smoking; and easier supervision and control. The greatest disadvantage of the continuous kiln is that it can be used only by the larger plants, its high first cost being prohibitive to smaller companies.

FUELS.

The fuels that can be used in burning clay products are wood, crude oil, coal, and natural gas. In Minnesota the fuel is usually wood or coal. A producer-gas plant is installed at one of the continuous kilns. The smaller plants nearly all use wood. Crude oil and natural gas are used only in regions where these materials are cheap or where wood and coal are not to be obtained. Natural gas is, however, the ideal fuel.

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BURNING PROCESS.

No matter what type of kiln is used, great care should be exercised in burning, and the temperature should be kept under constant control. Unfortunately, few of the smaller plants make any effort to measure the temperature obtained in the kiln. In the common scove kiln accurate measurements are impractical, but in the permanent downdraft kilns measurements could easily be taken, and the more frequent use of Seger cones or some other form of measurement is urged. (See Pl. XI, *A*, p. 88.) The practice of estimating the temperature from the settling of the upper corners of the ware or from simple inspection is not much better than a guess and is the cause of much waste.

The physical and chemical changes that take place in burning are dehydration (p. 34), oxidation, and vitrification (p. 36).[1]

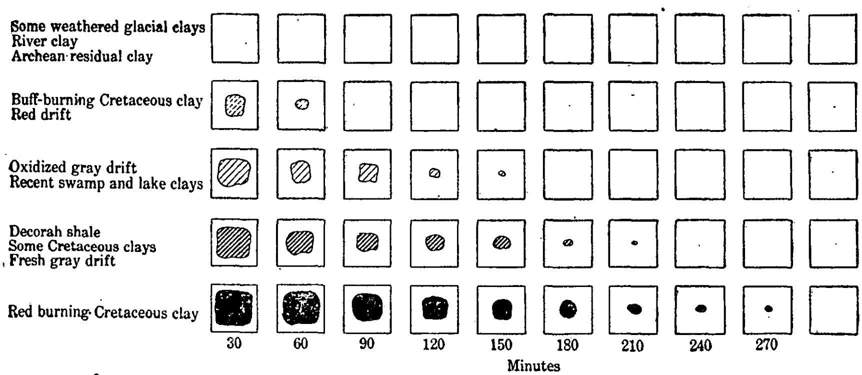


FIGURE 7.—Diagram showing the gradual oxidation and disappearance of black cores due to organic matter, when brick are kept at red heat.

Oxidation affects only clay that contains organic matter or iron. All common ware must be oxidized before being vitrified. More losses and trouble in burning are due to mismanagement at this stage than at any other, for if the clay begins to melt before oxidation is complete the evolution of gases usually puffs the ware out of shape. A black core or an appearance called "blue stoning" often results, even when no swelling occurs. (See fig. 7.) Lack of complete oxidation may be due to the density of the fine clay, the evolution of gases from the clay, an excess of fuel and gases, or too great thickness of pieces of clay to be oxidized. Vitrification is discussed on pages 35–37.

The rate of cooling should be carefully controlled. There is often as much danger from too rapid cooling as from too rapid heating. The percentage of loss from underburned, overburned, or broken

[1] Orton, Edward, Am. Ceramic Soc. Trans., vol. 5, p. 377, 1903.

products varies in kilns of different types but is directly dependent on the care exercised in burning. Overburned brick may at some plants be sold as the popular "klinker" brick and are even imitated by an artificial roughening process. (See Pl. II, *A*, *B*.)

Minor points in connection with burning are glazing, flashing, and efflorescence. 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; it depends on the regulation of the supply of fuel and air. Efflorescences may form in the kiln quite independently of any action of the soluble salts in drying, apparently as a result of the action of combustion gases in the kiln.

TECHNOLOGIC SUGGESTIONS.

The clay products shipped into Minnesota at present include much brick and tile of grades no better than those produced within the State. This seems to be the result of lack of equipment for producing large quantities and consequent inability to accept large contracts. Good-sized plants should install numerous labor-saving devices and better and more economical machinery. Special attention should be directed to washing, or to any other process that might make the widespread gray drift available for draintile. Experiments in mixing clays should be made for they may result in the development of some high-grade products. Other detailed suggestions are made in the county descriptions (pp. 111–251).

USE OF CLAY PRODUCTS.

Whether or not a brick or tile is satisfactory in practice depends not only on the method of manufacture and on the qualities of the raw material, but also largely on the skill with which it is used in construction. If brick are laid in poor mortar or in such a position that they are subjected to constant wetting and drying out again efflorescences are almost certain to appear. If tile are laid haphazard, without calculating the necessary grade and efficiency, they can not be expected to be satisfactory. If the best of brick are laid in a street without a proper foundation the pavement will not stand well. For these reasons the following notes may be of value to the users of clay products.

PAVING BRICK.

Brick and paving blocks of different sizes are probably more used in paving work than asphalt, stone, and wood blocks combined. They have many advantages, among which are ease of traction, good foothold for horses, minimum dust and mud, adaptation to all street grades, ease in repairing, ease in cleaning, slightness of absorption, pleasing appearance, and ease of laying.

Many towns in Minnesota use paving brick on their streets, but their general use has been greatly delayed because there are comparatively few localities in the State where such brick are manufactured. Clay suitable for paving brick is widespread in Minnesota, and no doubt when these deposits are developed the use of brick for paving will become much more common.

In some States, notably Ohio and Pennsylvania, paving brick are used for country highways, but it is unlikely that they will soon be put to that use in Minnesota, although there is sufficient clay in the State to insure a good supply.

The cost of brick pavement varies with the local conditions, but until recent years has been $1.50 to $2 a square yard, including a concrete foundation. The cost of maintenance can be kept down to the minimum by prompt repairs. When a soft brick shows signs of wear it should promptly be replaced by a good one, for a hole once started is rapidly enlarged by the wheels of passing vehicles, which break the surrounding bricks. The life of a good brick pavement is stated to be 15 to 20 years under moderate traffic. The brick are usually laid upon a 6-inch layer of Portland cement concrete covered by a 1-inch cushion of rolled sand. The brick are laid with their long dimensions at right angles to the curb, and either cement or asphalt is poured in the joints. They are then rolled to insure a firm setting, and are allowed to remain undisturbed till the cement has set.

DRAINTILE.

Soils which are not readily freed from an excess of water and which are suitable for agriculture should be drained. A closed drain is better than a ditch, for it is permanent and wastes no land. If the ground-water level is less than 4 feet below the surface for any length of time, the soil will have too much water and should be underdrained. Underdraining improves wet soils by permitting earlier working after rain, by permitting the deeper growth of plant roots, with corresponding increase of the portion of the plant above ground, by furthering the circulation of the air through the soil, producing chemical changes necessary to plant growth, and by permanently loosening the surface soil, with consequent attraction (by capillary power) of the deeper-seated ground water.

Tile drainage may be extended on land adapted to profitable farming until water from an ordinary rainfall is all passed down into the soil and the excess is carried away through the underdrains without injury to the growing crops and without surface washing of the land. This, of course, would involve a very considerable enlargement of the work, much more than has been contemplated by many farmers. In the early days of tile drainage the opinion was entertained by some that only the low, wet places, sloughs, or ponds needed this improvement of soil conditions, and a few people may be still of the same opinion; but the change among intelligent farmers and other landowners has been radical.

Thorough work in drainage involves the construction of underdrains in parallel lines, near enough together to affect the soil and the subsoil about alike, and to lower the water level to a point where it will not injuriously affect the growing crops and will permit the circulation of air through the soil and subsoil above the water level. The following suggestions are taken largely from an article by Billingsley:[1]

In planning to drain a field or any given area of land, the general surface configuration of the land should be carefully studied and levels taken. It is important to know definitely where the best outlet should be located to afford a free flow of water, and where the main and subordinate drains should be placed to insure the most efficient drainage. It is also important to know what fall can be had in the several drains, including the main and lateral drains, for the reason that drains having considerable fall do not require as large a tile as those having slight fall.

Again it is important to know the character of the soil and subsoil. If they are open, the lateral drains may be laid from 60 to 100 feet apart; if the soil or, more particularly, the subsoil is retentive or close, allowing the water to percolate only slowly through it, the drains need to be closer together (from 30 to 50 feet apart).

Still another important factor to be considered in the general plan is the amount of water that flows on to the land to be drained from land adjoining. This flow of water, if considerable, must be provided for by using larger tile for the drains that will necessarily carry it from the neighboring land.

After determining all these factors the entire system should be outlined on paper, including the levels, mains, submains, and lateral drains, the sizes of tile to be used, and the depth of the drains.

The work of construction properly begins at the outlet, which should be so placed as to give the greatest fall and most direct outflow of water. The main drain at the outlet should be as deep as conditions will allow or the perfect working of the system requires, not exceeding ordinarily 4 or 5 feet.

The size of the tile to be used depends upon the area to be drained, the inclination, or fall, the depth of the drains, and the character of the soil and subsoil. Prof. R. C. Carpenter has prepared the following estimate of the number of acres drained by tile of different sizes:

[1] Billingsley, J. J. W., Clay Worker, October, 1908, p. 386.

Number of acres drained by tile of specified sizes.

Inclination.	3-inch.	4-inch.	6-inch.	8-inch.	10-inch.	12-inch.
One foot in—						
50	8.4	17.0	47.7	98.0	170.4	296.0
100	5.7	11.9	33.1	69.2	120.6	190.5
150	4.5	9.5	26.6	56.0	97.3	154.4
200	3.9	8.2	22.8	48.0	83.9	132.5
250	3.5	7.5	20.4	42.4	74.4	117.0
300	....	6.9	18.4	38.2	65.5	107.0
400	....	5.9	16.5	34.6	60.3	90.7
500	....	5.2	14.8	30.1	54.0	81.6
600	....	4.8	13.3	28.0	48.6	74.0
800	....	4.1	11.4	24.0	41.9	65.0
1,000	....	....	10.2	21.2	37.2	56.0

To insure sufficient capacity to carry the water from 10 acres the use of tile at least 4 inches in diameter is recommended. Besides, it is claimed that larger tile give better aeration of the soil.

The depth of the drain also affects the size of the tile. Other conditions being equal, the greater the depth the smaller the tile required. Drains laid at the depth of 3 feet and 80 feet apart would afford very little drainage to the soil midway between the drains in a close, retentive clay soil but would probably be satisfactory in an open soil.

Ditches should be only wide enough to work in conveniently and at the bottom should be only wide enough to lay the tile. Tile laying is begun at the outlet and is continued up grade. Unevenness at the joints is to be avoided.

Lateral or side drains should enter the main drain at an acute angle, so that the water they carry will not interfere with the current of the main drain.

Minnesota has large areas of swamp land which when once drained raise excellent crops. Drainage with cylindrical clay tile has many advantages, and the manufacture of draintile should become of much greater importance in the next few years. Fortunately the State possesses an abundant supply of raw clays from which good tile can be made.

GEOLOGY OF MINNESOTA.[1]

By Frank F. Grout and E. K. Soper.

PHYSIOGRAPHY.

Minnesota is made up largely of gently undulating plains underlain by glacial drift alternating with belts where the surface is rougher, owing to the irregular heaping up of glacial drift as termi-

[1] For the main features of the discussion of the geology, credit is due to Winchell, N. H., and Upham, Warren, Minnesota Geol. and Nat. Hist. Survey Final Repts., 1884, 1888, 1899, 1900; and to Hall, C. W., and Meinzer, O. E., Geology and underground waters of southern Minnesota: U. S. Geol. Survey Water-Supply Paper 256, 1911.

nal moraines. In many places these moraines are bordered by nearly flat tracts underlain by sand and gravel deposited by glacial waters. Both these flatter areas and the moraines are pitted with abundant depressions, known as kettleholes. The hollows and many larger low areas are poorly drained, and in consequence lakes and swamps are very numerous, particularly in the north-central part of the State. In the northwestern part there is an extensive flat plain which was at one time covered by the waters of a great lake, known as glacial Lake Agassiz, and a much narrower area bordering Lake Superior was also flooded by the waters of a succession of temporary glacial lakes known as Lakes Duluth, Algonquin, and Nipissing. Though the mantle of glacial drift is generally thick there are numerous places, especially in the eastern part of the State, where the bedrock is exposed or but thinly covered.

Southern Minnesota, considered broadly, is a low plateau, the southwestern part of which reaches 1,900 feet above sea level, or 500 feet above the rest. This higher part extends into South Dakota and has been named the Coteau des Prairies. The next highest part of the plateau is in the southeastern part of the State, in Mower County, where the elevation is 1,400 feet above sea level.

In the southeastern counties the streams have cut deep gorges with precipitous walls. In much of this district the glacial drift is thin, and in the eastern parts of Winona and Houston counties there is no drift at all, this being part of the great Driftless Area of the upper Mississippi Valley. In these deeply dissected areas rock outcrops are numerous, and here and there are flat-topped mesa-like erosion remnants and rock towers like ancient castles. Most of the Driftless Area and some of the adjacent drift-covered tracts are covered by a thin veneer of dustlike clay, or loess, which ranges from 1 to 12 feet thick, averaging 4 or 5 feet. This loess tends to smooth over any small irregularities in the surface. It reaches its maximum thickness in stream valleys and depressions, and is absent from many of the higher knolls and rolling prairies.

Northern Minnesota possesses a more varied topography. The northwestern part, which was covered by glacial Lake Agassiz, is as flat as a floor, except for a series of low gravel ridges that represent former beaches of the lake. The north central and the northeastern parts are more undulating and contain numerous morainic belts. In the southern part of Otter Tail County three morainic belts converge to form the Leaf Hills, which rise 250 to 300 feet above the general elevation of the surrounding land. Otter Tail County also contains 430 lakes,[1] not including swamps and ponds—a greater number than any other county in the State. The extreme

[1] Terry, C. M., Minnesota Geol. and Nat. Hist. Survey Final Rept., vol. 2, p. 535, 1888.

northeastern part of the State has a rather rough topography and it includes the highest point in Minnesota. Here several low "ranges" of pre-Cambrian rock trend approximately N. 70° E. and rise from 1,800 to 2,000 feet above sea level.

The principal drainage system is that of Mississippi River and its intricate net of tributaries. In the northwestern part of the State Red River is the main stream; and in the northeastern part a considerable area drains to Lake Superior.

GEOLOGIC HISTORY.

The rocks of Minnesota range in age from the earliest Archean granites and schists to the Recent alluvium. The columnar section (Pl. IX) shows the principal formations in the State, arranged in the order of age, with the oldest at the bottom.

ARCHEAN PERIOD.

The Keewatin epoch was largely a time of volcanic activity. The basalt lava flows, which were both subaqueous and subaerial, were profoundly metamorphosed and softened to the so-called green schists over much of the area, both before and after the deposition of the Algonkian sediments. Small amounts of sediments were deposited, especially near the end of Keewatin time.

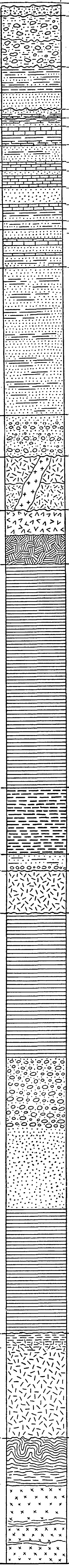
In Laurentian time acidic granitoid and gneissic masses were intruded into the Keewatin, mostly as great granite batholiths. Their relation to the Keewatin is complex, and some outcrops show evidence that the granite magma stoped and absorbed parts of the basic rock. North and northwest of Lake Superior the granite intrusions are enormous. The age of the granite on the southwest along Minnesota River is less certain.

After the Archean period closed erosion was long continued, the region was subjected to notable earth movements, and the rocks were metamorphosed.

ALGONKIAN PERIOD.

As a whole the Algonkian was a period of sedimentation as contrasted with the Archean, though marked igneous action occurred at intervals. Two main divisions of Algonkian rocks, each of considerable thickness are represented in Minnesota—the Huronian series below and the Keweenawan series above.

The earlier Huronian sediments, which have been called lower-middle Huronian, were clays and graywacke sands. Some igneous action also occurred at this time, yielding a variety of products. Deposition extended from northeastern Minnesota westward, and the



Era.	System and Series.	Group and Formation.	Section.	Character of Formation.	Approximate Maximum Thickness (Feet).	Clay-Bearing Value.
Cenozoic.	Quaternary. Recent.			Alluvium, etc.		Contains alluvial clays.
Cenozoic.	Quaternary. Pleistocene.			Glacial drift, boulder clay, sand, gravel, associated lake and river clays and loess.	500	Contains large amounts of good clay.
Mesozoic.	Cretaceous. (Upper Cretaceous).	Benton shale. Dakota sandstone. Basal Cretaceous clay.		Soft blue and gray shale and incoherent sands, white sandstone, and white clay.	500	Contains much high-grade clay. Fire clay.
Paleozoic.	Devonian.			Limestone and sandstone.	100	Contains thin beds of clay.
Paleozoic.	Ordovician.	Maquoketa shale.		Shale, dolomite, and sandstone.	100	Contains but little clay shale.
		Galena limestone. Decorah shale. Platteville limestone.		Limestone and shale.	230	Contains but little clay shale. Contains much good clay shale. Contains no clay.
		St. Peter sandstone.		White and yellow sandstone and some shale.	200	Contains no clay.
		Shakopee dolomite.		Yellow buff, pink, or red dolomite.	100	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.		Dolomite, shale, and sandstone.	200	Contains small amount of shale.
		Franconia sandstone.		Micaceous sandstone with green sand at base.	100	Contains no clay.
		Dresbach sandstone and underlying shales and sandstones.		Fine-grained white sandstone and shale; limestone beds toward base.	450	Contains some sandy shales.
(?)	Algonkian (?).	Red clastic series.		Red sandstone and shale.	1,750	Contains but little available clay or shale.
Proterozoic.	Algonkian. Keweenawan.	Conglomerate and sandstone.		Conglomerate and sandstone.	500	Contains very little clay.
	Algonkian. Keweenawan.	Eruptives.		Gabbro, diabase, and granite.	Unknown.	Contains no clay of value.
	Algonkian. Huronian.	Animikie group (upper Huronian). Acidic and basic intrusives.			Unknown.	Contains no clay.
		Animikie group (upper Huronian). Virginia and other slates.		Black to dark-gray carbonaceous slates.	3,000	Contains no clay except residuals. Slates may be used after crushing.
		Animikie group (upper Huronian). Biwabic and gunflint formations.		Taconite, iron ore, ferruginous chert, and paint rock.	800	Contains very little clay.
		Animikie group (upper Huronian). Pokegama quartzite.		Quartzite and quartz slate, conglomerate base.	200	Contains no clay.
		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.
		Lower-middle Huronian. Slates, graywackes, and conglomerates.		Green to gray slates, graywackes, and conglomerates.	5,000	Contains much slate but no clay.
	Archean. Laurentian.	Residual clay.		White residual clay; decomposition product.		
		Intrusive granites, gneisses, and porphyries.		Granites and porphyries in part altered to schists.	Unknown.	Contains large amounts of residual clay and kaolin beneath the drift.
	Archean. Keewatin.	Soudan formation.		Banded slates, cherts, and red jaspers; iron bearing.		Contains no clay.
		Green schists, porphyries, Ely and other green stones.		Greenstones, green schists, porphyries, and iron ore.	Unknown.	Contains no available clay.

GENERAL GEOLOGIC SECTION OF MINNESOTA.

beds may have covered most of the Archean area in the State, but they were later removed by erosion from much of the northern area. Further earth movement and metamorphism occurred.

The upper Huronian sediments (Animikie group) were deposited over a relatively plane, eroded surface of Archean and lower-middle Huronian rocks. The advance of the sea was marked by the deposition of thin conglomerate and sandstone, above which were laid down the iron-bearing formations of the Mesabi range, and above these some other slates. The abrupt change from sand to iron-bearing formation indicates a sudden change of conditions, probably to be explained by basic eruptions rather than by topographic or climatic changes.

The upper Huronian rocks are much less altered than the earlier rocks, but in central Minnesota were rendered schistose by the heat and pressure attending the intrusion of large volcanic masses, probably for the most part Keweenawan. The quartzite of the Minnesota River valley may have been deposited as sand at this time.

The Keweenawan epoch began and ended with normal sedimentation but included vigorous igneous action, both intrusive and extrusive. The sediments of this age are relatively thin, and most of them, from their red color, poor assortment, and alternation with lava flows, may be considered probably land deposits. Most of the material of the middle and upper Keweenawan sediments was derived from the dominantly basic Keweenawan igneous rocks. These sediments lie unconformably above the Huronian, but their exact relation to the Cambrian is not a simple problem. No profound metamorphism has occurred since the beginning of the Keweenawan epoch.

The Lake Superior basin was developed partly in Keweenawan time, and lavas now dip under the lake on each side. The large area on the north shore is of special interest on account of the great gabbro mass (Duluth gabbro) and the series of flows and intrusions easily studied in the shore cliffs. Granites and diabases, probably of the same age, extend southwestward to central Minnesota near Little Falls, and diabase dikes as far as the Minnesota River valley.

The red clastic series shown in the well records of the region around Minneapolis and St. Paul is regarded as probably Algonkian, though it may be Cambrian.

CAMBRIAN PERIOD.

Prolonged erosion at the end of Keweenawan time was followed by the deposition of a sandstone on the eroded slopes of all the earlier formations. Above the profound unconformity thus produced the strata vary little from the horizontal, furnishing a strong contrast with the earlier rocks. In some places, as at Taylors Falls, a sandstone in contact with tilted Keweenawan lavas contains marine fossils and is well up in the Cambrian. On the other hand, from Mora to Fond du Lac there is a sandstone with some shaly layers near the base that is nonfossiliferous and may be continuous with the upper Keweenawan sandstone. With this exception the sediments seem to be marine. A great basin in the southeast quarter of the State contains a series of Paleozoic rocks from the Cambrian up. In the middle of the Cambrian period some minor change of conditions caused the deposition of shale and magnesian limestone (the St. Lawrence formation), after which sandstone (the Jordan) was again deposited.

ORDOVICIAN PERIOD.

Without any apparent unconformity the deposition of sediments continued after the Cambrian. The lowest formations included in the Ordovician system are the Oneota and Shakopee dolomites, made up mostly of dolomite, with a few sandy layers and lenses.

Above these dolomites lies the St. Peter sandstone, 80 to 200 feet in thickness and consisting of very pure quartz in well-rounded grains. Locally a thin, shaly bed appears about 40 feet above the base, and another thin shale is very persistent between the sand and the overlying Platteville limestone.

The Platteville, usually 12 to 20 feet, but in places 30 feet thick, is a shaly magnesian limestone of variable quality.

Upon the Platteville was laid down the Decorah shale, which now crops out in places from the Twin Cities southeastward. The period of its formation favored alternately the deposition of shale and that of limestone, and the resulting rocks show variable alternating materials in layers from an inch to several feet in thickness. At St. Paul the exposed shaly beds are 80 feet thick, but farther southeast they thin considerably. With included limestone layers the maximum thickness of the formation is about 100 feet. The shales are green but weather brown from original pyrite. Fossils are numerous.

After the deposition of the shale with limestone layers there was a gradual increase in the proportion of limestone. The Galena limestone in Minnesota (including some shale layers) makes up 50 to 100 feet or more of the section. Because of absence of exposures its maximum thickness is unknown. Careful paleontologic work is needed to locate accurately the boundary between the Galena and the Decorah. However, no shales of value have been found much above the base of the Galena.

The Maquoketa shale is variable both vertically and horizontally, being full of sandy and calcareous lenses and irregular beds. It has a thickness of about 100 feet.

DEVONIAN PERIOD.

After a period of erosion 50 to 100 feet of Devonian sediments were deposited. These constitute the northern part of a large mass in Iowa. In Minnesota the main portion of the rock is sand and limestone, but it includes some shaly bands, and by long weathering has formed residual clays, as at Austin.

PRE-CRETACEOUS EROSION INTERVAL.

The period of erosion that followed the deposition of the Devonian rocks must have been long. Weathering was widespread and profound. No rocks are known which indicate any deposition of sediments in Minnesota until Upper Cretaceous time. No important diastrophic movements are indicated, and it is not probable that the elevation above sea level was great or that the topography was rough. In many places the Cretaceous and glacial deposits rest on earlier rocks which have been very deeply weathered. Archean granites and gneisses, extending over many counties, have been kaolinized to depths of 10 to 100 feet. If any considerable relief had existed when or after the weathering took place, erosion of these softened rocks would have been very rapid. The period of weathering is also indicated by the decay of Paleozoic sediments, yielding residual clays.

CRETACEOUS PERIOD.

The Cretaceous sea encroached upon Minnesota from the west and southwest, and Cretaceous clays and sands and in a few places limestone now unconformably overlie Archean, Algonkian, and Paleozoic rocks. The clays contain marine fossils of Benton age. The southwest quarter of Minnesota is almost entirely covered with such sediments, except for the prominent quartzite knobs which probably represent islands in the Cretaceous sea.

Occurrences in North Dakota and some thin deposits extending as far east as the Mesabi range have been thought to indicate that similar Cretaceous deposits underlie the drift in the northwest quarter of Minnesota. However, it is known from recent work of Frank Leverett[1] that Paleozoic sediments underlie the drift in this part of the State, and hence that any Cretaceous sediments that were de-

[1] Personal communication.

posited between the Mesabi and Dakota areas have been removed by erosion. From the Mesabi range along a belt extending through southwestern Minnesota, however, outcrops of Cretaceous beds are sufficiently numerous to justify mapping the formations as continuous, and well records and the drilling on the Cuyuna range confirm the connection.

Toward the southwest were accumulated as much as 500 feet of sediments that consist chiefly of impalpable clay and fine sand, such as would be derived from thoroughly weathered granites. Since the recession of the sea in late Cretaceous time the region has not been again submerged. Probably there was extensive erosion before Pleistocene time and during the ice invasions and the interglacial stages.

QUATERNARY PERIOD.

PLEISTOCENE EPOCH.

By Frank Leverett.

Just before the Pleistocene epoch began the larger features of the topography of Minnesota were much the same as now. The advance of the ice, however, scoured out some valleys, filled in others, and deposited drift over large areas, entirely changing the details of topography and drainage. The drift deposits over a large part of Minnesota west of Mississippi River above the mouth of the Minnesota are 200 to 300 feet thick and in places reach 500 to 600 feet. They are much thinner in the eastern and southern parts of the State, where over large areas there is only a mere trace of drift and in but few places does it exceed 100 feet. The retreat of the ice, by melting, formed marginal lakes and swollen, heavily silted streams, with further deposition and modification of topography.

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

The oldest glacial deposit, known as the pre-Kansan or Nebraskan drift, is almost completely buried beneath later deposits. The attenuated edge of this drift may be exposed outside the Kansan drift in the southeastern counties.

Clayey and silty deposits found in a few places under the Kansan drift may represent accumulation in the Aftonian interglacial stage. They are, however, thin and of small extent and are rarely seen in either natural or artificial cuts.

The Kansan drift is extensively exposed in the southeastern part of Minnesota and in Pipestone and Rock counties in the southwestern part. It is generally of clayey texture, but as a rule carries limestone pebbles. It contains local pockets or lenses of marly pebbleless clay.

Weathering has somewhat modified the character of the upper part of the Kansan drift, and wind has coated much of the surface in the southwest corner of the State and some of it in the southeast part with several feet of loess, a pebbleless deposit of fine dust. Recent wash has moved some loess and some drift down sloping hillsides and so mixed them that the precise mode of origin of some particular clay banks may not be easily determined. The possibility that some of the glacial clay may have been deposited at the Iowan or Illinoian stages of glaciation need not be considered in this connection.

The Wisconsin gray drift, which was deposited by an ice sheet moving from Manitoba across western and southern Minnesota, is largely of clayey texture, but, like the Kansan drift, contains many pebbles, a large part of which are limestone. In places some lenses and pockets of pebbleless clayey material are included in the stony clay.

The Wisconsin drift that was deposited by glaciers invading eastern and central Minnesota from the north and northeast is in large part stony and sandy and contains very few bodies of silt or clay.

Locally streams of water from the melting ice spread fine sandy clays over what are called outwash plains.

The lake silts laid down in bodies of water in the western part of the Lake Superior basin and in the Red River basin are in places very thick, as at Wrenshall, but generally there is only a thin deposit of lacustrine sediment in the deep pools of these old lake beds, and in certain localities there is only sand.

On the borders of the Lake Superior basin red boulder clay was deposited in large quantities; it is now dissected by steep gorges.

In addition to the great glacial lakes of the Lake 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 lies north of Princeton at the large plants of Brickton, and similar areas lie farther east along the northern border of a district which was occupied by a lobe of ice that extended northeastward from the Mississippi to the St. Croix Valley, above the Twin Cities. These clays were, in places, overridden by the later advances of the ice.

RECENT EPOCH.

Since the final disappearance of the Pleistocene glaciers there have been only slight modifications of the surface and very little accumulation of material or removal by erosion. A few lakes and swamps have been drained, and a few have been filled. The large river channels have been silted up.

GEOLOGIC FORMATIONS AND THEIR CLAY DEPOSITS.

ARCHEAN SYSTEM.

The rocks belonging to the Archean system in Minnesota consist of greenstones, granites, gneisses, schists, and small amounts of altered sediments (slate, jaspilite, and dolomite), which underlie all other formations and constitute the base upon which all subsequent strata were laid down. In northern Minnesota these Archean greenstones and granites crop out at many points and include the productive iron-bearing formations of the Vermilion iron range. In the western part of the State hornblende and biotite schists and granites underlie the Cretaceous formations in many localities, where they crop out or have been reached by deep wells. Granite and gneiss crop out in central Minnesota and are known by well records to underlie the greater part of southern Minnesota.

In the southwestern part of the State the upper portions of the Archean rocks that are covered by Cretaceous sediments are invariably decomposed to white clay, as is clearly shown in the numerous wells throughout the region and in the few outcrops. The clay is in places 50 feet thick and grades downward into rotten granite of various shades. Its upper portion grades upward into the Cretaceous sedimentary clays, and the dividing line between the two has rarely been determined. It is more than probable that the upper parts of some of the very thick bodies of white kaolin that have been reported are residual clays reworked into the Cretaceous sediments. The clay in these deposits was formed long after the Archean period, but the exact time is uncertain, and they will be referred to in this report as clays residual from the Archean.

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 these clays in Big Stone County at a depth of 250 to 600 feet, in Chippewa County at about 700 feet, and in Lac qui Parle County at 150 feet. Probably the clays are very extensive and continuous in the counties north and west, where well records are not available. However, if the pre-Cretaceous weathering affected the granites in the northern part of the State, erosion by ice probably removed all traces of the products.

The following analyses of the clay as mined and one of the clay after washing are available. (See also analysis of a decomposed gneiss, p. 17.)

Analyses of residual clays.

	1	2	3	4	5	6
Silica	43.86	45.92	41.71	62.04	37.88	60.05
Alumina			34.61	25.54	26.96	27.55
Ferric oxide	41.82	39.84	4.58	1.89	15.78	1.30
Ferrous oxide			6.88			
Magnesia	Very small.	Very small.	.22	....	1.74	.77
Lime			1.16	....	Trace.	.38
Soda	Not det.	Not det.	.11	....	.95	.31
Potash	Not det.	Not det.	Trace.			4.26
Water	14.65	14.12	12.69	....	15.88	5.30
Phosphoric oxide	....	....	....	....	....	.11

1. Clay from Morton; F. F. Grout, analyst. U. S. Geol. Survey Water-Supply Paper 256, p. 310, 1911.
2. Clay washed from a decomposed granite, Redwood Falls; F. F. Grout, analyst. U. S. Geol. Survey Water-Supply Paper 256, p. 310, 1911.
3. Clay from decomposed gneiss, Birch Cooley, near Morton; A. D. Meade, analyst.
4. Clay, partly analyzed by L. B. Pease.
5. "Fahlunite." Average of three analyses by S. F. Peckham. Minnesota Geol. and Nat. Hist. Survey, vol. 2, p. 196, 1888.
6. "Kaolin (Archean), green or pink to white decayed schist." Minnesota Geol. and Nat. Hist. Survey, vol. 5, p. 730, 1900.

This widespread residual clay can probably be used after washing for making porcelain and chinaware. A rough washing test in the laboratory on a few samples from widely separated localities shows that about 50 per cent of the crude product can be washed through a 100-mesh sieve. This finer fraction of the clay burns to a clear white, which even after being glazed darkens very little. These clays are the most refractory in Minnesota and are capable of being used for the highest grade of clay products. Their plasticity and tensile strength are low, and even if they are used only for brick they need a plastic bond. In firing they become hard at about cone 3 (2,200° F.), though in this respect they vary rather widely, and the temperature of viscosity is much higher. They remain porous to high temperatures.

ALGONKIAN SYSTEM.

HURONIAN SERIES.

In Minnesota two divisions of the Huronian series have been recognized—the lower-middle Huronian and the Animikie group or upper Huronian. These two divisions are separated by an unconformity, and the Huronian as a whole is separated by unconformities from the overlying Keweenawan and the underlying Archean.

The lower-middle Huronian includes no clays but consists of granites, granite porphyries, dolerites, slates, graywackes, and conglomerates and their metamorphosed equivalents. The sedimentary series attains a thickness of 5,000 feet in the northern part of the State. It lies unconformably upon the Archean and crops out in general in a belt around the Archean area, except where concealed under drift.

A number of distinct formations belong to the Animikie group or upper Huronian. Among these are the acidic and basic intrusive rocks, the Virginia and other slates and schists, the iron-bearing Biwabik and Gunflint formations, and the Pokegama quartzite. The Sioux quartzite is thought by some to be equivalent to the Pokegama quartzite and by others to belong in the lower-middle Huronian.

The Huronian rocks crop out only in the central and northeastern part of the State, except the Sioux quartzite, which occurs in the southwestern part. The slates cover the largest area and attain great thickness. Their mineral composition is very different from that of an average shale or slate.[1]

None of these Huronian rocks contain any clay deposits of importance, but experiments made in connection with the preparation of this report show that some of the slates exposed in Carlton County, when mixed with a small amount of common clay from the drift, will make a handsome fancy brick of high quality. They must be crushed, as they do not slake nor become plastic. The Sioux quartzite contains some layers of a silicified shale known as pipestone, but as none of them are more than 4 feet thick they are of no importance in the ceramic industries. Some layers of clay in the iron-bearing Biwabik formation are so ferruginous that they are called paint rock. This paint rock does not melt at a temperature as low as might be expected from its high content of iron. Where necessarily removed in the course of iron mining it can be used in brickmaking, though it is not especially desirable. An analysis may be found in the report on St. Louis County (pp. 225–230). Residual clays from mica schist crop out along Mississippi River in Morrison County, and though they are not so refractory as those from the Archean they fuse at a relatively high temperature. An analysis may be found in the report on Morrison County (pp. 197–200).

[1] Van Hise, C. R., and Leith, C. K., The geology of the Lake Superior region: U. S. Geol. Survey Mon. 52, p. 612, 1911.

KEWEENAWAN SERIES.

The Keweenawan series in the eastern and northeastern parts of the State is made up largely of flows of basic igneous rocks and includes no clays. Some of these flows alternate with sediments, which, however, were in large part derived from the flows and are highly ferruginous and feldspathic and not suitable for use as clay. At Two Harbors, on the north shore of Lake Superior, lenses of these sediments a few feet in length and a few inches in thickness were sampled to determine their exact character. An analysis of shaly sand rock, probably Keweenawan, is given in the report on Lake County (pp. 186–187). Along Snake River, just below Pine City, a larger bed of essentially the same material occurs. The clay from these deposits does not slake or become plastic, and it remains sandy and soft to a temperature of 2,300° F.

ALGONKIAN (?) SYSTEM.

RED CLASTIC SERIES.

Sediments known as the red clastic series, probably of the same age as the Keweenawan igneous rocks, are known in the eastern and southeastern parts of Minnesota and have been provisionally assigned to the Algonkian (?) system. In the south they underlie Upper Cambrian sediments and are known only from well records. They are probably of the same age as the red sandstone and shale (locally called Hinckley sandstone) that crop out unconformably above the Huronian from Lake Superior southwest to Mora. Shaly layers are especially abundant near the base of the red clastic series. An analysis of this shale from the vicinity of Fond du Lac is given in the report on Carlton County (pp. 134–140).

CAMBRIAN SYSTEM.

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

LOWER FORMATIONS.

The lower formations, including the older sandstones and shales, and the Dresbach and Franconia sandstones, are made up of 550 feet or more of fine-grained white sand with shaly beds and sandy shales and thin layers of limestone toward the base. The best exposures are along St. Croix River north of Stillwater and at Dresbach, on Mississippi River just north of the Iowa line. Siliceous shales of variable character occur at these places, but the deposits are not likely to be of importance as clays because of their small size and inaccessible position in river bluffs. Their behavior under firing is, however, not unfavorable.

ST. LAWRENCE FORMATION.

Overlying the Franconia sandstone is the St. Lawrence formation, which consists of buff-colored dolomite interbedded with shale and sandstone. The shale is greenish, and toward the top of the formation there are several thin layers of greensand. The total thickness of the formation is about 130 feet. The best outcrops are found along Mississippi and Root rivers, north of the Iowa line, but the formation underlies practically all of southeastern Minnesota, extending as far north as northern Washington County and westward to a point beyond Mankato, where it crops out in the Minnesota River valley. The shales are too thin to be of value as brick material. They are so sandy that they shrink very little up to the point of viscosity. The porosity can not be reduced below about 20 per cent.

JORDAN SANDSTONE.

The Jordan sandstone, the uppermost formation of the Cambrian system in Minnesota, consists of 75 to 200 feet of white to brown sandstone, without any clay. It is confined chiefly to the southeast corner of Minnesota, and its outcrops are best seen in the Minnesota River valley north of Mankato and in the bluffs along the Mississippi from Hastings to the Iowa line.

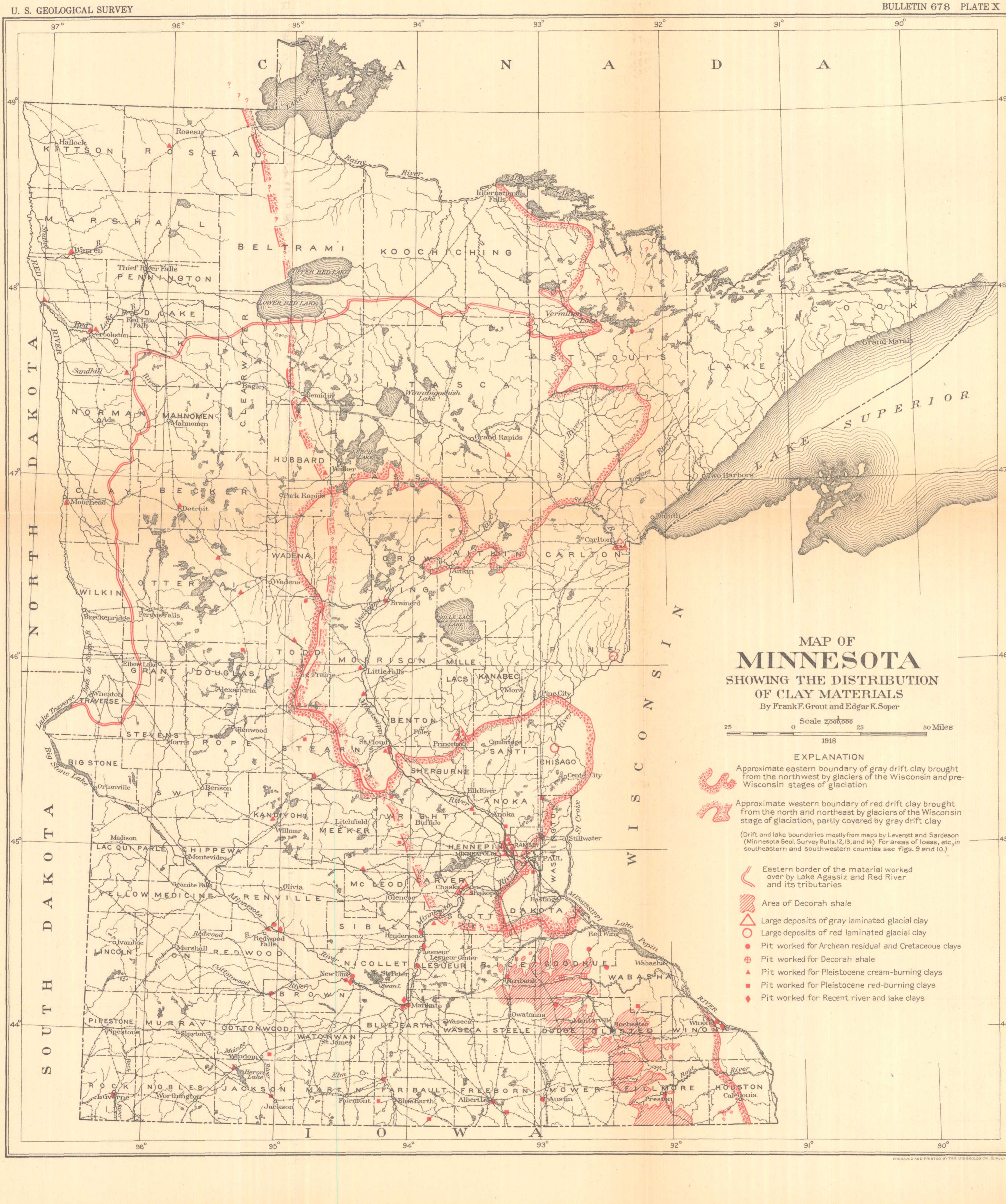
ORDOVICIAN SYSTEM.

The Ordovician system in Minnesota is composed of the following formations, named in order from oldest to youngest: Oneota dolomite, Shakopee dolomite, St. Peter sandstone, Platteville limestone, Decorah shale, Galena limestone, and Maquoketa shale.

The Ordovician rocks are confined to the central and southern parts of the State, where they rest conformably upon the Cambrian. They have a very slight general dip to the south.

ONEOTA DOLOMITE.

The Oneota dolomite is a buff to reddish dolomite that crops out in numerous localities along valleys and river bluffs in southern Minnesota. The texture of the rock ranges from compact to crystalline, but the crystalline variety is the more typical. The formation is from 75 to 200 feet thick. It contains no clay.



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SHAKOPEE DOLOMITE.

The Shakopee dolomite also contains no clays. It consists of a maximum of 100 feet of yellow, buff, or red magnesian limestone, which differs from the Oneota in color and in its finer grain and greater sand content. The Shakopee crops out along the Mississippi and Minnesota river bluffs. In much of south-central Minnesota it forms the surface upon which the drift has been deposited.

ST. PETER SANDSTONE.

The St. Peter sandstone consists in the main of a fine-grained, loosely consolidated white sandstone, which weathers yellow. It ranges from 80 to 200 feet in thickness, but the average is somewhat over 100 feet. In most parts of southern Minnesota the St. Peter is covered by either late Ordovician sediments or drift or by both, but it crops out along the Mississippi and its tributaries from Minneapolis south.

There is a 2-foot bed of shale at the top of the St. Peter sandstone, but it is of too small extent to be of value.

PLATTEVILLE LIMESTONE.

The Platteville limestone has an average thickness of 12 or 15 feet and reaches a maximum of 30 feet. The rock is a magnesian limestone that ranges in texture from compact to thoroughly crystalline and in color from buff to blue-gray. It crops out over large areas in southern Minnesota from the Twin Cities southeast. It contains no clay of value.

DECORAH SHALE.

Lying on top of the Platteville limestone is a series of green shales with a maximum thickness of more than 100 feet, though the common thickness is much less than this—probably not more than 50 feet. Interbedded with these shales are numerous layers and lenses of hard granular limestone, some of which are composed almost entirely of fossils. In places these limestone layers constitute more than one-half of the total thickness of the formation. They range in thickness from 1 inch to several feet, but most of them are less than a foot thick. At the base is usually a thick shale (about 10 feet), above which the shale and limestone alternate in similar layers. The shale is fissile and crumbles easily. The map (Pl. X) shows the area of workable Decorah shale but not the total extent of the formation. The upper part of the shale grades on the south into limestone.[1] The northern and eastern limits shown on the map are

[1] Sardeson, F. W., Galena series: Geol. Soc. America Bull., vol. 18, pp. 179–194, 1907.

eroded outcrops. On the west and south the Cretaceous and Devonian rocks overlap the Decorah and make it inaccessible, and even in the area where it is mapped the glacial drift covers some of it so deeply that it is quite beyond reach. In the extreme southern part of Minnesota the formation thins to about 30 feet. At Cannon Falls, as at St. Paul, it reaches a maximum thickness, but north of St. Paul it is entirely eroded away. Throughout the southern part of the State it is very gently folded, and its elevation above sea level ranges from 1,000 to 1,300 feet.

The Decorah is one of the most valuable clay formations in Minnesota. The shales, when crushed and pulverized and mixed with

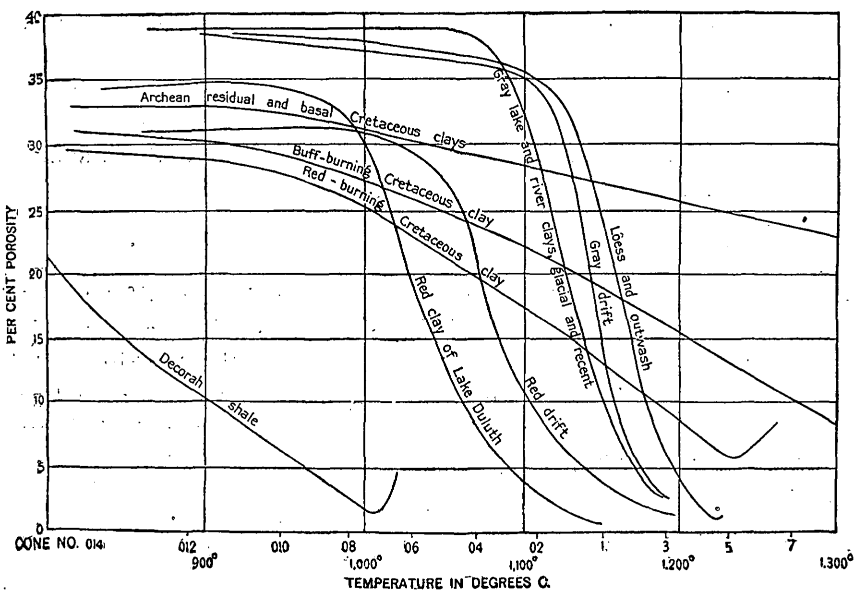


FIGURE 8.—Diagram showing the decrease in porosity with increasing temperature exhibited by average clays of the several geologic formations in Minnesota. (Compare with figs. 3 and 4.)

water, yield a greenish plastic clay that is used extensively near St. Paul and in Goodhue County for the manufacture of pressed brick, fancy brick, hollow ware, draintile, and common brick. The St. Paul plants are the most favorably situated in respect to markets, but others might be developed at Faribault, Rochester, and Cannon Falls. The high grade of the product eliminates most of the competition with common brick.

The plasticity of the Decorah shale is very high, but its shrinkage is not excessive. The tensile strength of the dry clay is about 125 pounds to the square inch, and the linear air shrinkage is 8 per cent. In general the shale burns red, but it can be burned green and brown or mottled by reduction during firing. It requires a much lower temperature for vitrification than most clays, about 1,800° F., but has a good range between incipient fusion and viscosity (see fig. 8), and therefore can be easily vitrified without loss.

The fire shrinkage is not excessive. Paving brick have not been produced from the Decorah, but they may yet be made from it. When burned at a little over 2,000° F. it produces klinker brick. The upper layers of the Decorah differ slightly in color and behavior from the lower ones. In many outcrops this shale contains so much organic matter that careless burning of it will result in "black cores." Care must be used to attain complete oxidation. Even if oxidation is long continued and thorough, gases are evolved at high temperatures (probably from the reactions of sulphur and iron), which cause swelling and deformation. These can be avoided by careful control of the burning. An unsightly efflorescence (kiln-white) also appears on some products, but it is seldom of great extent and was not seen in any brick burned to a high temperature. Analyses of the Decorah shale are reported in the discussion of Dakota County (pp. 149–153).

The shale is exposed in only a few places and should be sought by the stratigraphic method of prospecting. (See p. 50.) The top of the shale is likely to be marked by series of springs on grass-covered hillsides. Tests made at 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 to the square inch, and partly vitrified bricks with a rather high porosity still evident have a strength of over 3,100 pounds to the square inch.

GALENA LIMESTONE.

The Galena limestone overlies the Decorah shale or in part grades into it. (See fig. 33, p. 207.) It consists of granular or massive limestone that caps the hills in the southeastern part of Minnesota but is exposed in few places, owing to the loess and drift covering. In typical outcrops, as in Fillmore County, it contains only a few beds of shale, which are of no value, as they are but a few inches thick and shale free from limestone could hardly be obtained from them. Fragments of the dry shale slaked in three minutes to small lumps. The plasticity and tensile strength of the shale are fairly high. It requires 22 per cent of water for molding. Its air shrinkage is 5 per cent. At low temperatures the burning results 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 (2,210° F.) and turns gray at cone 6 (2,282° F.) but is still undeformed at even higher temperatures, though wholly melted at cone 12. The lime in the soft-burned bricks slakes and destroys the product.

MAQUOKETA SHALE.

The Maquoketa shale in Minnesota is an alternation of dolomitic shale and limestone, with shales too thin to be of value. Outcrops are known only in Fillmore County, where it 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 and its air shrinkage less than 3 per cent. It can safely be dried with artificial heat. Several samples burned to the temperature of cone 2 were buff in color, showed no fire shrinkage, and had an absorption of 27 per cent. The clay does not become hard at cone 3 (2,174° F.), and it becomes viscous at cone 6 (2,282° F.) and therefore can not possibly be burned to a hardness approaching vitrification. Only one sample of the Maquoketa shale was available.

DEVONIAN SYSTEM.

The Devonian rocks in Minnesota, which consist of not more than 100 feet of sandstone and limestone with some shale, overlie the Ordovician unconformably. They are confined to the extreme southern part of the State (Mower, Fillmore, and Faribault counties), into which they extend from Iowa. The shales are not of specially high quality and are too thin to be of much importance as a source of clay. In the vicinity of Austin marly layers of the Devonian have been used to mix with an overlying plastic clay, which has been described as Cretaceous but which may be residual from Devonian rocks.[1] The effect of the added lime is to improve the working quality and lighten the color.

Where Bear Creek crosses the line between Fillmore and Mower counties the shale beds were found to be as much as 1 foot thick and to show every indication of extending over considerable territory. They are yellow to buff in color, are 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 surprising plasticity, considering their sandy appearance. They require about 20 per cent of water for molding. Their tensile strength is nearly 100 pounds to the square inch. They can be dried rapidly without danger of cracking, and they retain their tensile strength even after being cut apart and pressed together. Their 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, as indicated in the table.

[1] Sardeson, F. W., The so-called Cretaceous deposits in southeastern Minnesota: Jour. Geology, vol. 6, p. 679, 1898.

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
06	Buff		27
2	do	1	23
5	do		

The clay becomes hard at cone 03 (1,994° F.) and viscous at cone 6 (2,282° F.).

CRETACEOUS SYSTEM.

GENERAL CHARACTER.

The Cretaceous rocks found in Minnesota consist of soft sandstones, shales, and clays and locally have thin beds of conglomerate at the base. They lie immediately below the drift in much of the western part of the State and also in numerous scattered areas in the southern, central, and northern parts. Outcrops are few on account of the drift cover, but numerous well records have helped to show their general distribution. Their maximum thickness in Minnesota is about 550 feet. Their upper portion is composed chiefly of soft blue or gray shales and clay (Benton shale); lower down they consist of white sandstone and kaolins (representing the Dakota sandstone). In a few places in the northern part of Minnesota a Cretaceous conglomerate containing pebbles of hard hematite lies at the base of the shale overlying beds of iron ore. In the western part of the State the Cretaceous rocks rest upon the decomposed Archean granites and gneisses; the base of the shale is white clay of conglomeratic or concretionary texture that 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 variations in the bedrock indicates that the white clay is colluvial.

The Cretaceous beds contain the highest-grade clays found in Minnesota. Some of these clays are used for stoneware, pottery, sewer pipe, and fire brick. At present few good bodies of Cretaceous clays that lie close enough to the surface to be profitably excavated are known, but it is very probable that more detailed prospecting in the drift in the vicinity of Cretaceous areas would result in the discovery of other deposits of valuable clay. For convenience in discussion the pebbly or concretionary basal clays of the Cretaceous will be treated separately, and many references will be made to the residual clays from the Archean, from which the basal clays can not always be sharply distinguished. The higher formations are shales of much more ordinary appearance.

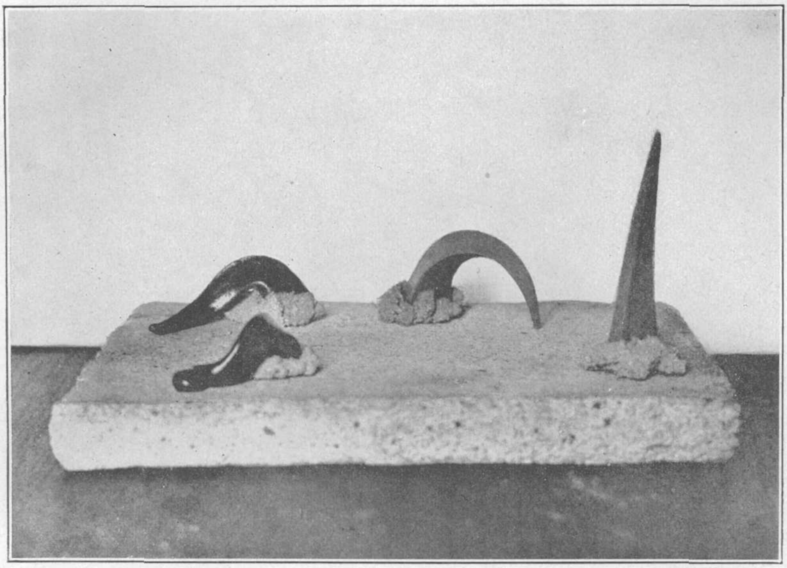
BASAL CRETACEOUS CLAYS.

The basal Cretaceous clays are most prominently exposed in the bluffs on both sides of Minnesota River from Granite Falls to New Ulm and probably to Mankato. Apparently similar white clays are found under the drift in several counties on either side of this strip along the river. Their great extent under the drift is thus further confirmed, and the certainty that they are not entirely Archean residual clays is shown by their stratified character and their development from Huronian schists near Richmond, in Stearns County, and near Bowlus, in Morrison County.

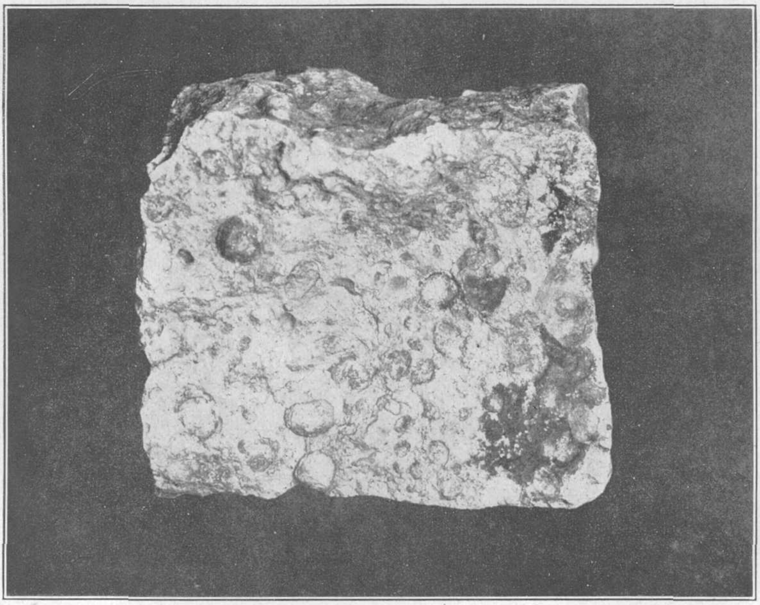
There is a general variation in the character of these basal Cretaceous clays as traced through these outcrops and farther north. Where the Archean or other bedrock formations are feldspathic, the basal conglomerate consists largely of clay. At Bowlus, farther north, the basal Cretaceous has the appearance of an iron-stained clay and is shown by analysis to be high in iron. Still farther north, on the iron ranges, the Cretaceous basal conglomerate immediately overlying the Huronian iron-ore deposits is good iron ore. This gradation, evident from the study of a series of scattered outcrops, may be taken as some slight indication of the continuity and contemporaneous formation of the various materials.

The clays that crop out in the Minnesota Valley, however, are not wholly conglomeratic but appear to be concretionary. (See Pl. XI, *B*.) The rounded spots show only a little concentric structure and are at some places more highly colored than the matrix and at others less highly colored. In a very few instructive outcrops these rounded spots, which appear to have the same composition as the matrix, are associated with rounded quartz pebbles. It is therefore concluded that not all of them are concretionary. Part of them may be waterworn fragments. Possibly the original pebbles were quartz and feldspar, and the feldspar was subsequently altered, as the bedrock below was altered. Analyses of several samples show high alumina. The sample from Bowlus (see section on Morrison County, pp. 197–200) certainly contained too much alumina for the mineral kaolinite and may have contained concretionary bauxite that 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.

Most of the basal Cretaceous clays are highly refractory, fine grained, and rather siliceous, and some of them are greatly contaminated with hematite. Their plasticity is low, and their tensile strength in the dry state is generally not over 50 pounds to the square inch. Their shrinkage both in drying and burning is very small. They become steel-hard at temperatures ranging from cone 06 to cone 35.



A. SEGER CONES AFTER HEATING TO THE TEMPERATURE OF THE THIRD CONE OF THE SET.



B. CONCRETIONARY OR PEBBLY CRETACEOUS CLAY.

Analyses are given in the descriptions of Morrison, Redwood, and Stearns counties (pp. 197–200, 216–220, 233–237). The whiter clays could probably be washed to produce a kaolin fit for chinaware.

LATER CRETACEOUS SHALES.

The later Cretaceous shales are thought to underlie much of the western part of Minnesota, but are covered with a thick mantle of drift over most of the area. Beyond their eastern border, which can not be accurately mapped on account of the drift cover, there are many outliers and patches that have been transported bodily by ice.[1] These include some of the most valuable deposits in the State. In places the shales are interbedded with sandstone and less commonly with limestone. Nearly all the shales are light to dark gray, but some have a greenish tint. They are exceedingly plastic and have a peculiar waxy feel, apparently related to the occurrence of some mica scales in the clay. They overlie the basal conglomerate with an abrupt change in structure and color. Many of them are contaminated with organic matter and many are somewhat ferruginous. Their thickness in any place depends on the depth to which they have been eroded. Outcrops show vertical banks ranging from 1 to 50 feet in height and well records reveal much greater thicknesses. In the southern and southeastern parts of the State the shales are semi-refractory, but in the western and northern parts they are more uniformly ferruginous and are not so valuable. Nearly all the Cretaceous shales have a good range of vitrification and can be burned hard without danger of fusion.

The buff-burning Cretaceous clays require 27 per cent of water for molding. Their air shrinkage is less than 7 per cent, their plasticity is fair, and their tensile strength is 170 pounds to the square inch, high enough for the production of the most elaborate and complex forms constructed in Minnesota. On burning many of the clays become dense and hard below 1,900° F. Their shrinkage on burning to thorough vitrification is only about 5 per cent. The absorption is 5 per cent after the clay becomes hard. Several of the clays, though burning very dense, give indications of withstanding high temperatures without losing any of their strength, the range of vitrification being over 500° F., probably higher than that of any other of the common clays of Minnesota. (See fig. 8, p. 84.)

These shales are utilized in Goodhue and Le Sueur counties (pp. 165–173, 187–191), and their quality is shown by the reputation of the stoneware made at Red Wing. Tests show that some clays not now

[1] Sardeson, F. W., The so-called Cretaceous deposits in southeastern Minnesota: Jour. Geology, vol. 6, p. 679, 1898.

used are similar in properties to some that are used with excellent results. The following analyses are typical:

Analyses of buff to white burning Cretaceous shales.

	1	2	3	4	5	6	7	8
Silica	69.92	69.84	68.298	69.050	59.72	70.10	87.70	68.70
Alumina	17.39	23.07	18.266	18.830	30.00	16.99	7.24	18.04
Ferric oxide, Ferrous oxide	1.68	.48	2.867	2.607		Trace.	Trace.	1.53
Lime	.60	.11	.719	.296	.82		.67	1.24
Magnesia	1.11	.14	.802	.622	.51		.07	.56
Sodium oxide	.07	Trace. (Sodium and potassium oxides)	.81	1.066			3.17	.24
Potassium oxide	2.25		.60	1.461		10.69	.49	5.28
Phosphorus oxide								.09
Sulphur trioxide						.23		
Titanium	.63							
Moisture	1.10	6.35	1.29	.898	10.34	1.98	Trace.	1.40
Ignition	5.45		6.155	4.912			Trace.	
	100.20	99.99	99.807	99.742	101.39	99.99	99.34	97.08

1. Red Wing, Goodhue County. Clay sampled at stoneware plant. F. F. Grout, analyst.
2. Red Wing, Goodhue County. Analysis reported by J. H. Rich to Heinrich Ries.
3. Red Wing clay. Sample from Minnesota Stoneware Co., Red Wing, Apr. 22, 1902. C. P. Berkey, analyst.
4. Red Wing stoneware clay, air dried. C. P. Berkey, analyst.
5. Ottawa. Ottawa Brick Co. Ries, Heinrich, Clays; their occurrence, properties, and uses, 1906.
6, 7, and 8. Minnesota Geol. and Nat. Hist. Survey Final Rept., vol. 1, p. 438, 1884.
6. Near Mankato. Clay filling hollows in Shakopee dolomite.
7. Near Mankato (sec. 20). White clayey bed of considerable extent.
8. Near Mankato. Clay or shale between Shakopee dolomite and Jordan sandstone in L'Huillier Mound.

The red-burning Cretaceous shales are approximately the same as the buff-burning shales in slaking, tensile strength, and air shrinkage. Their plasticity is high. The water of plasticity is 29 per cent. They burn hard at about 1,800° F., with a linear fire shrinkage of 2 per cent and an absorption of 15 per cent. They reach viscosity at a temperature of about 2,200° F., thus having a range of vitrification of nearly 400° F. (See fig. 8, p. 84.) The absorption of well-burned brick can be reduced below 5 per cent, and the linear fire shrinkage is then about 7 per cent. Care must be used in oxidation to avoid black cores and swelling. This description applies to clays not now used as well as to several from which excellent brick are made.

Bricks are made from these Cretaceous shales by both soft-mud and stiff-mud methods. Soft-mud solid red brick show a compressive strength of 3,600 pounds to the square inch. Stiff-mud hollow brick, made light in weight for shipping, show compressive strengths of 900 to 1,600 pounds to the square inch, the strength depending on the degree of vitrification. The modulus of rupture is from 500 to 1,500 pounds to the square inch. Typical analyses are given below. Plants making use of these clays are described in the reports on Brown and Goodhue counties (pp. 126–134, 165–173).

Analyses of red-burning Cretaceous shales.

	1	2	3	4
Silica	63.65	61.32	58.14	73.34
Alumina	17.27	12.27	19.40	14.75
Ferric oxide	....	3.62	5.52	} 5.45
Ferrous oxide	4.75	4.18	....	
Lime	1.21	.99	.79	.28
Magnesia	.06	1.76	1.52	.05
Soda	.91	.42	.54	Trace.
Potash	2.47	3.59	2.09	Trace.
Barium oxide	....	.05	....	....
Manganese oxide	....	.27	....	....
Phosphorus oxide	....	.27	....	....
Sulphur	....	.19	....	....
Titanium oxide	.62	.66	.68	....
Moisture	2.03	....	2.10	....
Loss on ignition	7.36	10.73	8.81	4.71
	100.33	100.32	99.59	98.58

1. Gray shale, west of Springfield. F. F. Grout, analyst.
2. New Ulm, Minn. Brick clay, U. S. Geol. Survey Bull. 60, p. 151, 1890. T. M. Chatard, analyst. A brick made from this clay is reddish brown, strongly sintered, somewhat fractured. Sample taken by John Lind on south bank of Cottonwood River on section line at river crossing, east of wagon-road crossing, south of New Ulm.
3. Clay sampled by A. Parker, of Brown Valley, Minn., just beyond the State line in South Dakota. F. F. Grout, analyst.
4. Red ochery clay, near Mankato. Minnesota Geol. and Nat. Hist. Survey Final Rept., vol. 1, p. 438, 1884.

TERTIARY SYSTEM.

Rocks of Tertiary age have not been certainly recognized in Minnesota. Numerous thin stream deposits that are probably of this age can not be differentiated from the more recent surficial deposits. Most of them have been worked over by streams or by the ice and have been mixed with the material of the drift.

QUATERNARY SYSTEM.

PLEISTOCENE DEPOSITS.

GENERAL CHARACTER.

With reference to their ceramic value, the Pleistocene deposits of Minnesota may be subdivided as follows: Nebraskan drift (no clay); Aftonian (?) interglacial deposits (only thin clays); Kansan and Wisconsin drift from the northwest (the gray drift); Wisconsin drift from the north and northeast (the red drift, including as a special phase some red boulder clay deposited west of Lake Superior by the combined action of ice and water); laminated lake and river clays (including earlier gray or yellow weathered clays and later red clays); outwash; and loess. These subdivisions are based on differences in character, and a single subdivision (as the gray drift) may include material deposited by two or three separate invasions of the ice. The red drift from the north differs somewhat from that from the northeast, but the associated clays are so much alike that no distinction is made between them.

AFTONIAN (?) INTERGLACIAL DEPOSITS.

After the early or Nebraskan ice invasion vegetation apparently spread over the southern part of Minnesota and formed a dark-gray soil from 1 to 4 feet thick, which has been buried under more recent deposits of gray drift. Though too thin to be of economic value, the soil could easily be traced for perhaps 20 rods in a clearly defined outcrop along the Chicago, Rock Island & Pacific Railway about 2 miles southeast of Faribault. Two analyses of it were made in 1906 by F. F. Grout, as follows:

Analyses of Aftonian (?) soils.

	1	2
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	.82	.60
Alkalies, etc., by difference	3.19	3.01

GRAY DRIFT CLAYS.

Glacial drift, consisting largely of clay, generally gray, with a surficial alteration to yellow, covers more than half of Minnesota. Apparently it was brought from the northwest by glaciers, which in a few places reached the eastern border of the State. The map (Pl. X) shows its general distribution, but the area delineated includes some local sandy areas in which there is little or no clay. The gray drift may be the product of more than one ice invasion, but the clays do not differ sufficiently to permit correlation of the type with the age. Several samples of Kansan drift gave much the same results as the more abundant material of Wisconsin age.

Most of the gray drift contains abundant limestone pebbles, which were probably derived from the Devonian limestone far to the northwest. In most places the drift is covered only by a few inches of soil. Loess may have accumulated over much of the area, but on hillsides it is in many places mixed with surface wash and is not readily differentiated. Loess mixed with pebbles is not distinguished from the gray drift in this discussion. The methods by which such clay with limestone pebbles can be used are described on pages 55–56.

In general clays found in the gray drift slake in two minutes and require 24 per cent of water for molding. Their plasticity is high and their tensile strength is 150 pounds to the square inch. They can be rapidly dried without serious injury. Their air shrinkage is 5 per cent, and their fire shrinkage is only 1 per cent at the time the clay becomes steel hard and about 6 per cent before it becomes viscous. The absorption meanwhile ranges from about 21 per cent down to 6 per cent. The average clay becomes steel-hard at cone 02 (2,030° F.), and viscous a little above cone 3 (2,174° F.). The range of vitrification is therefore less than 150° F., and it is usually unsafe to burn the clays very hard. (See fig. 8, p. 84.) On the other hand, after the clay has been burned at moderate temperatures the lime pebbles it contains slake and destroy the product. The unoxidized gray clay is essentially like the surface yellow clay but may shrink a little more and requires more care during oxidation. The properties of the clay can be greatly improved by the removal of the limestone—the washing or "slumming" process used at Hutchinson and the dry-cleaning process used at Jackson are recommended for careful investigation by all who desire to utilize the gray drift. For some clays simple grinding will be sufficient, but washing is much more certain and of much wider application. Analyses of the drift and washed drift are given in the report on McLeod County (pp. 191–193). Brick and tile made from this drift are salmon-colored at low temperatures and buff at higher temperatures. Crushing tests made by the experimental engineeering department of the University of Minnesota show an average strength of over 2,400 pounds to the square inch. Draintile made from washed gray drift is exceptionally resistant to frost.

As the northern part of Minnesota becomes more settled, and as the farms in all parts of the State find tile drainage desirable, the increasing local demand for a good quality of tile such as can be produced from this gray drift will warrant the construction of several plants with half a dozen downdraft kilns each. The marketing radius of such a plant would be rarely over 50 miles. Nearly every region in the western half of the State in which the demand is at all favorable will undoubtedly be found to be supplied with gray drift of the proper quality. Burning tests without cleaning, made at a dozen widely separated points in the State, were not at all conclusive; and more information was obtained by washing the drift through sieves and determining the proportion of sand to clay and the percentage of lime in the clay, these being the important factors. The sand caught on the 100-mesh sieve at these points ranged from 23 to 33 per cent; at Hutchinson it was 30 per cent. The lime (CaO) ranged from 6 to 11 per cent; at Hutchinson it was 9 per cent. Most of the samples were closely similar to the Hutchinson material. Some of the washed clays burned salmon and some buff, but all were hard at cone 02. It is therefore safe to say that throughout about half of Minnesota this drift material is available for the production of high-class draintile at a commercial profit unless it has to meet the local competition of some purer clay.

Locally drift clays may be largely affected by the character of the bedrock passed over by the ice just before it deposited its load. An example is found near Goodhue, in Goodhue County, where much Cretaceous clay is incorporated in the drift.

GRAY LAMINATED LAKE AND RIVER CLAYS.

In many parts of Minnesota, chiefly along the valleys of Minnesota and Mississippi rivers and their tributaries, there are beds of glacial clay which are stratified in distinct, nearly horizontal layers 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. In many places these beds are interlaminated with thin layers of fine sand. They tend to split along the darker partings, which extend continuously without grading into one another. The beds are nearly level but may dip a few degrees in either direction or may even be locally folded into arches or basins. Some clean exposures show 60 layers, all similar, in a depth of 5 feet. It is evident that these were produced by varying conditions. Deposition of sand alternated with deposition of clay a great many times, the changes in sedimentation being due possibly to seasonal variations in the water of the glacial streams. Along the flood plain of an ordinary river clay settles only in hollows outside the path of the main current. The structure of this clay and its occurrence only in glaciated regions, or valleys drained from glacial drift, indicate that it was formed by large streams probably coming from a melting ice sheet.[1] Such streams flow in greater volume and carry coarser sediments in summer than in winter and might thus have produced the alternating layers.

Such clays have long been known and used along Minnesota River at Chaska and Jordan and along Mississippi River from Minneapolis to Brainerd. They are calcareous and are suitable mainly for common brick and for fireproofing. The clay of Wrenshall is similarly laminated. (See Pl. I, p. 20.) 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.

In general the gray laminated clays have fair plasticity and require 27 per cent of water for molding. Their tensile strength is about 120 pounds to the square inch and is not seriously affected by rapid dry-

[1] Winchell, N. H., The geology of Minnesota: Minnesota Geol. and Nat. Hist. Survey Final Rept., vol. 1, p. 467, 1844; vol. 2, p. 132, 1888. Berkey, C. P., Laminated interglacial clays: Jour. Geology, vol. 13, p. 35, 1905.

ing. Their air shrinkage was shown by the tests to be about 5 per cent, but this average figure is too high, for the samples include some of the underlying blue joint clays, which are not used in manufacturing. When the clay is first burned hard the fire shrinkage is only a little over 1 per cent, but the maximum shrinkage observed before viscosity averages about 8 per cent. The absorption at the temperature at which the clay becomes hard is about 25 per cent, and this drops to 7 per cent before the product is in danger of melting. The average clay burns hard at cone 02 (1,994° F.) and becomes viscous at cone 3 (2,174° F.). These figures, though better than those for the gray drift, show a rapid fusion and the clay should not be used in attempts to make vitrified products. (See fig. 8, p. 84.) An analysis is given in the discussion of Anoka County (pp. 113–118). The clay is suitable for common brick and hollow ware, usually of cream color, and makes fireproofing of excellent quality.

In the northern part of Minnesota large bodies of similar laminated clays occur in less accessible localities, as along the Bigfork and Littlefork rivers in and near Koochiching County. Samples from widely separated outcrops show surprising uniformity, though some laminated deposits are more sandy than those sampled. The clays are a little better in quality than those farther south, and they constitute a natural resource of future importance. They were formerly mapped as Cretaceous, but the present field studies show clearly that they are Pleistocene. This determination is corroborated by the character of the clay, which shows a much more rapid vitrification than any Cretaceous samples tested. The analysis also furnishes evidence of closer relation to glacial clays than to Cretaceous clays in other parts of the State.

The clays slake in a few minutes and yield with 33 per cent of water, a mass of high plasticity. The air shrinkage is 9 per cent and the tensile strength 160 pounds to the square inch. They become hard at cone 04 (1,958° F.) and reach viscosity at cone 3 (2,174° F.), having thus a range of vitrification of over 200° F. The absorption can be reduced from 20 per cent nearly to 1 per cent, and the fire shrinkage is then 8 per cent. A sample from Net Lake Rapids, on Littlefork River, was analyzed by A. W. Gauger with the following results:

Analyses of gray laminated clay of northern Minnesota.

Silica	47.70
Alumina	13.58
Iron oxides	6.51
Magnesia	3.13
Lime	11.70
Soda	1.05

Potash	2.34
Ignition	13.23
Moisture	1.79
Titanium oxide	.31
	101.34

RED DRIFT CLAYS.

The red drift lies generally in the eastern part of Minnesota, from Dakota County on the south to Lake County on the north. It is most conspicuous in counties that touch the border, and in the region of Mille Lacs, Brainerd, and St. Cloud, in Morrison and adjacent counties it extends westward to and beyond Mississippi River.

In the areas shown on the map (Pl. X) between the western boundary of the red drift and the eastern boundary of the gray drift, the red drift is overlain by a thin layer of gray drift. Much the larger part of the red drift is sandy and gravelly, but it contains locally valuable deposits of clay.

In general, the red drift, even where not pebbly, is more sandy and not so plastic as the gray drift but is still satisfactory. It requires 20 per cent of water for molding. The tensile strength is over 140 pounds to the square inch and is only slightly decreased by rapid drying. Shrinkage on drying is 4 per cent, and fire shrinkage ranges from 1 per cent at the time the clay becomes hard to 6 per cent at complete vitrification. The absorption is only 15 per cent when the clay is burned hard and can be reduced to 4 per cent or less. The average clay begins to vitrify at cone 04 (1,958° F.) and reaches viscosity at cone 3 (2,174° F.) It has thus a range of over 200° and can safely be burned to a vitrified brick, as has long been done at Coon Creek. (See fig. 8, p. 84.) Other deposits farther north are similar to that at Coon Creek. The excellence of the products is demonstrated by the tests made in the experimental engineering department of the University of Minnesota, which show the brick to have a crushing strength of over 7,000 pounds to the square inch. Rattler tests indicate that they would be satisfactory for paving. (See the report on Anoka County, pp. 113–118.)

RED LAMINATED LAKE AND RIVER CLAYS.

Along the eastern border of Minnesota and extending a considerable distance into Wisconsin are a series of deposits of laminated clay that have a striking red color, though otherwise similar to the gray laminated clays previously described. There can be very little doubt that their origin was dependent on the same seasonal alteration of sand and clay deposits brought by water from the melting ice sheet.[1]

[1] Berkey, C. P., Laminated clays: Jour. Geology, vol. 13, p. 35, 1905.

In general, the red glacial lake and river clays have low plasticity, which is developed by 21 per cent of water. Their tensile strength is less than 100 pounds to the square inch, but they can be safely dried with artificial heat. The air shrinkage is 4 per cent. The clays become steel-hard at cone 04 (1,958° F.) and reach viscosity at cone 2 (2,138° F.). At 1,958° F. the fire shrinkage is 1 per cent and the absorption 20 per cent. Before they reach viscosity the fire shrinkage may increase to 8 per cent and absorption may be reduced to less than 2 per cent. These red-burning clays should be exploited sufficiently to do away at least partly with the need of importing material of this type from Wisconsin. The extensive brick works at Menomonie, Wis., from which the Twin Cities and other parts of Minnesota receive large quantities of red brick, use laminated red clays exactly like those found in eastern Minnesota. The clays may also be used as a slip or glaze for colored semirefractory stoneware.

The following analyses, mostly of Minnesota material, show the general character of the clays:

Analyses of red laminated lake and river clays.

	1	2	3	4	5	6	7	8	9	10
Silica	57.79	58.52	64.76	77.7	77.00	82.50	77.00	77.00	77.00	77.00
Alumina	12.63	14.98	15.45	3.4	1.50	7.50	9.00	8.50	9.00	9.00
Iron oxide				3.5	7.00					
Titanium	.82									
Magnesia	4.11	3.39	4.02							
Lime	3.33	5.26	4.22	8.2	a 12.00	a 7.75	a 10.75	a 12.00	a 11.50	a 10.75
Soda	1.75									
Potash	2.71									
Loss on ignition	2.50	7.92	5.96							
Moisture	6.10			7.2	2.50	2.25	2.75	2.50	2.50	2.75

a Determined by difference; includes trace of magnesia.

1. Red laminated clay, Pine County. F. F. Grout, analyst.
2 and 3. Laminated clay, Grantsburg, Wis. Berkeley, C. P., Jour. Geology, vol. 13, p. 38, 1905; 2, Mixture of layers worked, fairly representative; 3, from uppermost layers.
4 to 10. From bed of tripoli at Stillwater. Analyses by J. R. Eckfeldt at United States Mint, Philadelphia. Minnesota Geol. and Nat. Hist. Survey Final Rept., vol. 2, pp. 394-396, 1888. 4, Position in bed not given; 5, upper stratum of lower bed; 6, small shaft at lower bed; 7, dark seam through lower bed; 8, middle of 20-foot exposure; 9, water line of 20-foot exposure; 10, upper exposure on the creek.

RED CLAYS OF LAKE DULUTH.

The retreat of glacial ice fronts toward the north and northeast probably occupied thousands of years. When the ice had vacated the western part of the basin of Lake Superior and the southern part of the Red River valley and while it still blocked the former, the obstructions caused the accumulation of immense lakes. Around the west end of Lake Superior are large deposits of a very sticky plastic red clay, with some sand grains and pebbles, apparently formed during one of the high stages of the lake known as Lake Duluth. Frank Leverett[1] says that the deposits accumulated as moraines laid down

[1] Personal communication.

in water, a mode of origin somewhat different from that of the laminated clays. Such red clay was formerly used for brick at West Duluth and for a short time at Superior, Wis. It appears from the bricks now to be seen in the old buildings that the clay was not burned at sufficiently high temperature to make hard brick. Some of the deposits require more water to make them plastic (50 per cent) and show greater air shrinkage (12 per cent) than any other Minnesota clays tested. They burn hard at cone 08 (1,814° F.) and become viscous at cone 1 (2,102° F.), which means that they can be vitrified with reasonable safety. Absorption can be reduced to less than 2 per cent. The immense shrinkage is the main defect, but this can be partly corrected by additions of sand or slate. (See description of Carlton County, pp. 134–140). The clays are sufficiently fine grained and fusible to make satisfactory slip glazes.

Analyses of the red clay of Lake Duluth.

	1	2
Silica	53.390	50.51
Alumina	14.259	15.89
Iron oxides	13.706	8.21
Lime	3.033	7.10
Magnesia	1.740	5.14
Potash	Not det.	1.87
Soda		1.66
Titanic acid	....	.26
Loss on ignition	14.273	7.35
Moisture	....	2.44
	100.451	100.43

1. Cook County, C. P. Berkey, analyst.
2. Carlton County, A. W. Gauger, analyst.

OUTWASH CLAYS.

In some parts of Minnesota, especially in the area of the red drift, there are glacial outwash plains that contain sandy but valuable clays. Few of these clays have been developed, but they are of fine quality. They slake at once, and with 25 per cent of water they show low plasticity. Their air shrinkage is 4 per cent, and their dry tensile strength is 120 pounds to the square inch. The range of vitrification is from cone 02 (2,030° F.), where they become hard, to cone 5 (2,246° F.), where they become viscous. The absorption can be reduced from 20 to 4 per cent with an accompanying fire shrinkage of 8 per cent.

LOESS.

The loess of Minnesota is generally considered a wind-blown deposit. It is composed of mineral derived chiefly from the glacial drift. Its origin appears to be similar to that of sand dunes, but loess, being finer grained than sand, is carried farther by the wind.

In Minnesota the largest deposits of loess occur in the southeastern counties near the Driftless Area. It also occurs in the southwestern corner of the State (figs. 9 and 10). Over the uplands the loess ranges from 2 to 4 feet in thickness, but in the valleys and especially on the terraces along the sides of the valleys it is much thicker. At a great many of the small brick plants in the State the main deposit of clay is overlain by loess, and the two are mixed for the manufacture of brick.

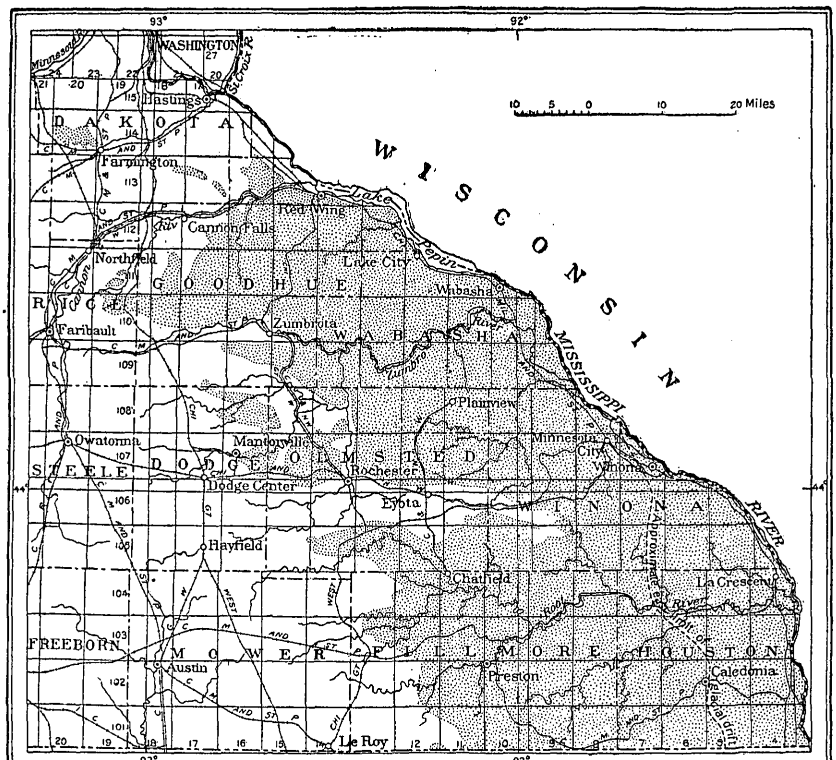


FIGURE 9.—Map of southeastern Minnesota showing an area (dotted) in which the drift is largely covered with loess. Data by Frank Leverett. The loess mantle is nearly continuous except along the larger valleys.

In general the loess clay is very uniform. The plasticity is low, and the water required for molding is 23 per cent. The tensile strength is over 100 pounds to the square inch. The air shrinkage is 3 per cent. The fire shrinkage during vitrification increases from 1 to 7 per cent, and the absorption decreases from 20 to 3 per cent. The range of vitrification is over 200° F., from cone 02 to cone 5. (See fig. 8, p. 84.) An analysis is reported in the discussion of Fillmore County (pp. 158–162).

Tests were made on loess clay bricks by the engineering department of the University of Minnesota. The crushing strength was not uni-

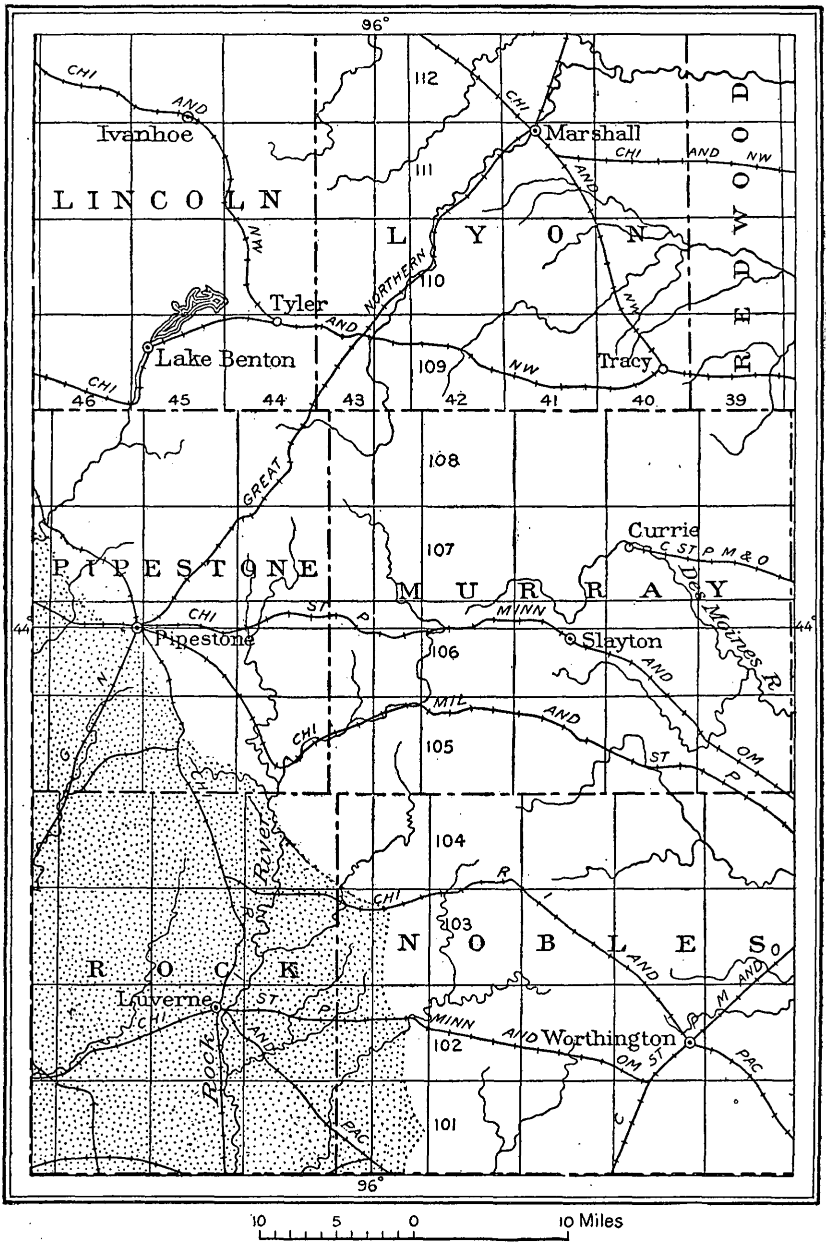


FIGURE 10.—Sketch map of the southwest corner of Minnesota showing an area (dotted) of old gray drift outside the young gray drift; part of this is loess covered. From map of southern Minnesota by Leverett and Sardeson.

form and was apparently greater in wet than in dry bricks; the minimum strength is 1,300 and the maximum 3,800 pounds to the square inch. The average absorption is 15.6 per cent, and the modulus of rupture is 582 pounds to the square inch.

CLAYS OF RED RIVER VALLEY.

The lake formed when the receding ice front dammed the northern outlet of the Red River basin is known as Lake Agassiz; its shore lines are marked by beach ridges and to some extent by the delta deposits formed by the incoming streams. (See Pl. X.) The deposits of Lake Agassiz do not seem to consist as largely of clay as those formed in the Lake Superior basin. The drift on each side of the Lake Agassiz basin has a moderately rolling surface. Within the area covered by the lake the plain is very smooth and nearly flat, yet the drift shows only slight traces of stratification. Wave action piled up ridges of sand and gravel along the shores and washed away the finer-grained material, depositing it as clay farther from the shore. These clay deposits were evidently small, as they are hardly perceptible 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 over the entire valley. At the present time much of the area of stratified clay is covered by the higher floods of Red River, and probably no part of it is more than 10 feet above the high-water line of Red River or its tributaries. As the river may have been much larger about the end of the glacial epoch, it seems clear that the clays were deposited as alluvium, partly in glacial and partly in recent time.

The thickness and width of the clays of Red River increase northward. At McCauleyville the deposit is about 2 miles wide and 50 feet deep, and at Moorhead and Fargo it is many miles wide and 100 feet deep. 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, except in the upper part, where, throughout most of the valley, it is leached to depths of 1 to 10 feet; the deepest leaching is in the northern part of the valley. Over the clay is a thin layer of black loam.

Only the yellow subsoil has been employed for the manufacture of brick. Most of this leached portion is quite free from the limestone pebbles, is less plastic, and dries more safely than the lower portion. On account of its tendency to crack in drying the lower clay is spoken of as a joint clay and is very little used, though it forms much the largest portion of the whole mass. Across the line in North Dakota, where the material is of exactly the same quality as in Minnesota, a sample of joint clay was taken and tested by the North Dakota Geological Survey, with the following result:[1]

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.	Shrinkage.	Absorption.
010	Orange-pink	0	30.3
05	Pink	0.3	30.9
03	...do	0	30.3
01	Green	(a)	10.1

[a] Failed by cracking.

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.

In general the clays of the Red River valley developed high plasticity with 30 per cent of water. Their tensile strength is 120 pounds to the square inch but is somewhat reduced by rapid drying. The air shrinkage is 8 per cent, and the fire shrinkage increases from 1 to 8 per cent during vitrification. The absorption, meanwhile, decreases from 24 to 8 per cent. Vitrification begins at cone 03 (1,994° F.), and viscosity is reached at cone 3 (2,174° F.). Analyses are given in the report on Polk County (pp. 211–214).

Strength tests have been conducted on brick from these Lake Agassiz deposits by E. B. Jack, of Winnipeg. They have an average crushing of 2,860 pounds to the square inch, a minimum of 2,365 pounds, and a maximum of 3,760 pounds on five bricks tested. Five hollow bricks gave an average of 706 pounds to the square inch. Surfaces of the brick were planed off and pressed between blotting paper. Bricks manufactured from the silts of Red River, when tested in the laboratory of the University of Minnesota, showed a crushing strength of 1,300 pounds to the square inch, an absorption of 33.3 per cent, and a modulus of rupture of 364 pounds to the square inch.

RECENT DEPOSITS.

RIVER CLAYS.

The chief deposits of river clay in Minnesota lie along Minnesota River, but Mississippi and St. Louis rivers also have a number of

[1] North Dakota Geol. Survey Fourth Bienn. Rept., p. 186, 1906.

these deposits, and many of the smaller streams contribute smaller amounts. The deposits along the Red River valley are discussed under a separate heading (pp. 101–102).

In general, the alluvial clays in Minnesota have fair plasticity, though nearly all of them are sandy. The average clay requires 25 per cent of water for molding, and its tensile strength is about 130 pounds to the square inch, even if rapidly dried. The air shrinkage is 5 per cent and the fire shrinkage from 1 to 7 per cent during vitrification. The absorption of the brick is about 21 per cent when it first becomes very hard—at about cone 02 (2,030° F.). Viscosity is reached at cone 4 (2,210° F.), with absorption reduced to 6 per cent. The composition of the alluvial clay is probably represented by an analysis of the clay at Le Sueur, made by A. W. Gauger, and a mechanical analysis by Mark Bray. This clay is in the middle of a series of brickyards along the river.

Analyses of alluvial clay of Le Sueur.

Chemical analysis.		Mechanical analysis.	
Silica	62.20	Total clay	24.90
Alumina	7.77	Silt	38.00
Iron oxide	4.53	Total sand	37.10
Magnesia	3.18		100.00
Lime	7.21		
Soda	3.58		
Potash	1.63		
Ignition	9.27		
Moisture	2.15		
Titanium oxide	.41		
	101.93		

Mr. Bray made some chemical tests also on the fractions obtained by his mechanical analysis. The most noteworthy discoveries were that the coarser material contained more silica (sand), and the finer material more iron and aluminum. The finer portion also had the most alkalies, but this variation was not regular nor marked.

A fairly representative sample of bricks made from the alluvial clays of Minnesota River, when tested at the engineering laboratory of the University of Minnesota, showed a crushing strength of more than 1,300 pounds to the square inch, even when 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 to the square inch; sand-mold common brick, 1,560 pounds to the square inch; wire-cut hard-burned brick, 6,010 pounds to the square inch.

LAKE AND SWAMP CLAYS.

For the most part the sedimentary deposits of the recent lakes do not differ very greatly from those of the lakes of glacial time. The surface of the surrounding country still consists of the red and gray drift which furnished the sediments when the glaciers were melting away. Some slight differences, however, may appear, for during glacial time the melting ice furnished immense volumes of water that have not been duplicated since. Erosion and filling of the lake beds have also tended to decrease the size of the bodies of water.

In general, the recent lake clays slake at once and become highly plastic. The water required for molding is 28 per cent. The tensile strength is 140 pounds to the square inch and only slightly less if rapidly dried. The shrinkage on drying is 6 per cent, and the fire shrinkage from 1 to 7 per cent during vitrification. The absorption at the beginning of vitrification is 20 per cent. Vitrification occurs between cone 04 and cone 3, a range of over 200°, and absorption decreases to 3 per cent. An analysis is given in the report on St. Louis County (pp. 225–230). The city building inspector of Minneapolis has made tests on hollow brick and tile made from a lake clay that burns salmon at low temperature and cream color at steel hardness. The hollow tile have an average crushing strength of 230 pounds to the square inch, and the hollow brick an average strength of about 260 pounds to the square inch. A test by the experimental engineering department of the University of Minnesota on some brick made with three vertical holes to decrease weight showed an average strength of 3,000 pounds to the square inch. The modulus of rupture was 374 pounds to the square inch and the absorption 31.4 per cent.

GEOLOGIC AND ECONOMIC SUMMARY OF CLAY DEPOSITS.

The geologic succession of the clays of Minnesota and their economic characteristics are set forth in the following table. Their behavior under vitrification is concisely shown in figure 8 (p. 84). The distribution of the geologic types of clay is shown in part on the map (Pl. X).

Approximate average results of tests of the clays of the principal geologic formations in Minnesota.

	Number of tests.	Time required for slaking.	Plasticity.	Water of plasticity.	Tensile strength.	Linear air shrinkage.	Fusion.		Range of vitrification.	Linear fire shrinkage.		Absorption.	
							Incipient.	Viscous.		At incipient fusion.	At viscosity.	At incipient fusion.	At viscosity.
		Minutes.		*Per cent.*	*Pounds per square inch.*	*Per cent.*	°*F.*	°*F.*	°*F.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Archean residual clay	4	2	Lean	....	30	4	2,138	2,800+	**700±**	2	5	20	10
Cambrian shale	6	Many.	....do	18	40	3	1,994	2,216	**252**	0	3	20	8
Decorah shale	15	5	Very high	30	125	8	1,778	2,102	**324**	4	6	15	7
Cretaceous:													
Basal clay	10	Many.	Lean	26	50	4	2,282	3,150+	**900±**	3	6	19	6
Buff-burning shale	10	4	Fair	22	170	6	1,886	2,462	**576+**	1	5	16	5
Red-burning shale	15	3	High	29	160	8	1,814	2,210	**396+**	2	7	15	5
Pleistocene:													
Gray drift	25	2	....do	24	150	8	2,030	2,174	**144+**	1	6	21	6
Gray laminated clay (south)	50	2	Fair	27	120	5	1,994	2,174	**180+**	1	8	25	7
Gray laminated clay (north)	10	6	High	33	160	9	1,958	2,174+	**216+**	1	8	20	1
Silt of Red River valley	10	3	....do	32	120	8	1,994	2,174+	**180+**	1	8	24	8
Red drift	7	2	Fair	20	140	4	1,958	2,174+	**216+**	1	6	15	4
Red laminated clay	5	1	Low	21	80	4	1,958	2,138+	**180+**	1	9	20	2
Red clay of Lake Duluth	5	2	Very high	40	60+	10	1,814	2,102+	**288+**	3	12	19	2
Outwash	5	1	Low	25	120+	4	2,030	2,246+	**216+**	1	8	20	4
Loess	5	1	....do	23	170+	3	2,030	2,246+	**216+**	1	7	20	3
Recent:													
River clay	10	1	Fair	25	130+	5	2,030	2,210+	**180+**	1	7	21	6
Lake and swamp clay	20	2	High	28	140+	6	1,958	2,174+	**216+**	1	7	20	3

STATISTICS OF CLAY PRODUCTS.[1]

The value of Minnesota's clay products, exclusive of pottery, in 1917 was $2,197,664. The principal clay product of the State is common brick, and during 1917 the manufacture of 86,606,000, valued at $656,247, was reported. This output constituted 30 per cent of the value of all of Minnesota's brick and tile products. Draintile was second among the State's clay products and was valued at $579,461. Carver County was the largest producer of common brick in 1917, Carlton County second, and Hennepin County third. Goodhue County was the leading clay-working county of the State, Hennepin County second, and Carver County third.

Clay products of Minnesota, 1911–1917.

Product.	1911	1912	1913	1914	1915	1916	1917
Brick:							
Common—							
Quantity	153,015,000	129,604,000	129,261,000	132,688,000	107,473,000	118,090,000	86,606,000
Value	$868,037	$760,983	$800,441	$883,791	$675,146	$772,696	$656,247
Average per M	$5.67	$5.87	$6.19	$6.67	$6.28	$6.54	$7.58
Vitrified—							
Quantity	(a)	(a)	(a)	(a)	(a)	(a)	(a)
Value	(a)	(a)	(a)	(a)	(a)	(a)	(a)
Average per M	$13.16	$16.34	$15.85	$16.12	$14.18	$8.87	$14.00
Front—							
Quantity	10,853,000	11,555,000	13,392,000	16,413,000	17,157,000	19,014,000	13,600,000
Value	$135,085	$144,125	$163,380	$208,624	$205,519	$243,246	$194,800
Average per M	$12.45	$12.47	$12.20	$12.71	$11.98	$12.79	$14.32
Fire........value	(a)	(a)	(a)	(a)	(a)	(a)	(a)
Draintile........do	$121,965	$126,690	$110,543	$143,194	$255,347	$422,809	$579,461
Sewer pipe........do	(a)	(a)	(a)	(a)	(a)	(a)	(a)
Fireproofing........do	$109,812	$160,804	$170,214	$123,911	$125,595	$153,486	$233,851
Tile, not drain....do	(a)	....	....	(a)	....	....	....
Stove lining	....	....	....	....	....	....	(a)
Pottery (earthenware and stoneware). value	(b)	(b)	(b)	(b)	(b)	(b)	(b)
Miscellaneous.....do	$458,579	$418,438	$536,439	$585,366	$384,306	$472,125	$466,382
Total value	$1,693,478	$1,611,040	$1,781,017	$1,944,886	$1,645,913	$2,064,362	$2,197,664
Number of operating firms reporting	81	79	69	65	66	55	52
Rank of State	21	21	20	15	16	16	18

a Included in "Miscellaneous."
b The value of pottery products for Minnesota could not be included in the State totals without disclosing the operations of individual establishments.

DISTRIBUTION OF TYPES OF CLAY.

REFRACTORY CLAYS.

ARCHEAN CLAYS.

Refractory Archean residual clays crop out in the neighborhood of Redwood Falls, Redwood County, and at Richmond, Stearns County, and probably extend under the drift from one locality to the other and also widely on the west to many points where well records show white clay. They may reach 50 or 100 feet in thickness. Some begin

[1] Middleton, Jefferson, Clay-working industries: U. S. Geol. Survey Mineral Resources, 1916, pt. 2, p. 551, 1918.

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.

CRETACEOUS CLAYS.

The basal Cretaceous clays occurring from Bowlus, Morrison County, to Redwood Falls, Redwood County, are the best refractory clays known in Minnesota. As they crop out at Richmond, Mankato, and elsewhere, they must extensively underlie the drift. The white clays shown by the well records mentioned above are no doubt at least in part Cretaceous. The greatest thickness exposed at the surface is 18 feet at Birch Cooley, near Morton, Renville County. The best material is that near Redwood Falls; the clay farther north is more ferruginous but is nevertheless refractory.

The higher Cretaceous clays at several points in Brown County and thence to Ottawa, in Le Sueur County, where an attempt was once made to use them, are also highly refractory. Along 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 deserve more careful prospecting than it has received.

SEMIREFRACTORY CLAYS.

VITRIFYING LIGHT-BURNING CLAYS.

Cretaceous shales are the only semirefractory light-burning clays in Minnesota. 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 temperatures so low as to leave them very near the nonrefractory class. The deposits worked at Clay Bank and Belle Chester are disturbed and apparently transported remnants of a larger formation some distance to the northwest, which, if it still exists, is covered with drift. 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, and the method should be applied in further work in both directions, though it is likely that the main sources of the clay may now be more deeply drift covered than the transported masses. These clays are the most valuable yet developed in Minnesota.

West of these points much of the Cretaceous shale is nonrefractory, but the character of the deposits at Austin, in Mower County, and near Essig, in Brown County, shows that the conditions for the development of the semirefractory type were widespread and that there is every reason to expect similar clays to be discovered under the drift in the intervening counties. The clay at Austin has been only partly 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 semirefractory, but they melt suddenly and are not likely to become important.

NONREFRACTORY CLAYS.

VITRIFYING CLAYS.

The great formations that yield nonrefractory vitrifying clays are the Decorah shale, the Cretaceous shales, and the Pleistocene red drift. These clays, without exception, have a good range of vitrification. Recent lake clays also show a fairly good range. Some other Pleistocene and Recent clays have a good range, but most of them do not. The Huronian slates when mixed with a small amount of red drift clay show a range of vitrification that makes it possible to burn them into excellent fancy brick. These slates crop out conveniently near Duluth along St. Louis River.

The shales of the great red sandstone of Keweenawan or Cambrian age crop out in so few places and are so thin that they are not likely to be developed, though their quality seems to be excellent.

The Decorah shale of Ordovician age uniformly gave favorable results. All the ground samples had a range of more than 200° F. during vitrification, and some had a range of 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 very carefully mapped. (See figs. 19, 22, and 32.) The western and southern limits shown do not indicate the farthest extension of the shales but the approximate limits of accessibility where the shales dip under Cretaceous or Devonian rocks. Even within these limits 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.

The Cretaceous shales are known to underlie the surface over much of the western half of Minnesota, though they are concealed by a thick covering of drift except in scattered places. They extend as far east as St. Louis, Stearns, and Goodhue counties. All of them vitrify gradually to a low porosity.

Associated with the semirefractory clays at the Red Wing pits are some nonrefractory clays of about equally good range. Still less refractory clays are found a little farther 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 semirefractory shales also occur. Along the bluffs of Minnesota and Cottonwood rivers, from New Ulm to Springfield, many large bodies of shale crop out and will no doubt be developed. The overburden may delay the exploitation of some of this shale, but that which is free from overburden, as at Springfield, would make excellent vitrified ware. The color of the product is much lighter for some clays than for others and in well-vitrified ware ranges from buff to reddish brown.

A large body of similar shale crops out 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 from the southwestern counties. Their character can be judged by a sample from Browns Valley, Traverse County, which burns red with an excellent range of vitrification.

The Pleistocene red drift has been used with remarkably good 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, where 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 at Coon Creek red drift is covered with gray drift shows that overburden is not an insurmountable difficulty. Much of the red drift is too sandy for clay products, but where there is not too much sand and the pebbles are not too numerous it warrants more extensive development. Points on the Soo Line east of Aitkin are worthy of consideration. All samples tested have a satisfactory range of vitrification.

The map makes no distinction between the red drift from the north and that from the northeast. The latter, which occurs mostly in Pine and Carlton counties, is equally good where it consists largely of clay. The water-laid drift in Carlton County has an excellent range of vitrification, but its temperature of fusion is low and it requires some sand for molding.

Gray drift is rarely suitable for hard brick until purified by removal of the pebbles.

A very few gray laminated clays fall in the nonrefractory vitrifying class. A few samples burned red instead of the common cream color and had a fairly good range of vitrification. Among these are the clays near Aitkin and one or two that were so much weathered that the lime may have been leached out. A larger body of laminated clay with a fair range of vitrification is represented by many outcrops along Littlefork and Bigfork rivers in inaccessible parts of

Koochiching County. These deposits constitute a valuable future source for northern Minnesota.

The loess at a few places in the southeastern counties shows a satisfactory range of vitrification, but it can not 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 of vitrification. In any part of Minnesota the clays of swamps or lake shores are worthy of attention, especially if the deposits can be easily drained.

CLAYS THAT MELT SUDDENLY.

Nonrefractory clays that melt suddenly are good only for common brick, draintile, fireproofing, or slip glazing. Besides minor formations too thin to be of economic value, this class includes nearly all the gray drift clays and about seven-eighths of the gray laminated clays and silts of Lake Agassiz and of the river silts. A few silts, which burn red, have a better range of vitrification. All the red laminated clays and some of the loess and the river alluvium are of this class.

The area of the gray drift is shown on the map (Pl. X). It is not to be expected that pebbly clay in this area will make good common brick unless treated. (See p. 55.) After treatment it may make not only brick but excellent draintile.

The gray laminated clays occur within the area of gray drift as mapped and at a few places outside that area, where a stream crosses from the gray drift to the red. For example, there are gray clays along Mississippi River from Brainerd to St. Cloud and at Wrenshall and vicinity, although in both the areas red drift is the main deposit.

Red laminated clays occur mostly along St. Croix River but are known in St. Paul near Mississippi River and in Floodwood, St. Louis County, near 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 abundant in southeastern Minnesota, and is rather widespread in the southwestern part also, though so mixed with surface wash as not to be clearly identified everywhere.

The deposits of Lake Agassiz and Red River occupy a strip along the river extending northward from Traverse County. They increase both in width and depth toward the north.

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

CLAYS OF MINNESOTA, BY COUNTIES.

AITKIN COUNTY.

Clay-bearing formations:
- Recent:
  - Alluvium.
  - Lake and swamp clay.
- Pleistocene:
  - Gray laminated clay.
  - Red drift.

At Aitkin there apparently existed a large depression into which Mississippi River and its glacial predecessor have brought great quantities of fine-grained clay. The surface for many miles is praccally a flat swamp and for considerable distances on both sides of the Mississippi is subject to occasional floods. The river and its tributaries have cut their channels only a few feet below the general level, and at low water as much as 8 feet of laminated clay may be seen in these shallow gorges. The deposits exposed are somewhat sandy, are yellowish gray, and have probably been formed in part by the present river. Well records show that the deposits extend to great depth and contain only a few sandy layers.

In secs. 24, T. 46 N., R. 27 W., at the northeast edge of Aitkin, a brickyard was started about 1890 and the company was reorganized in 1900, but the production has been small. The pit is so close to the banks of the river that probably a considerable proportion of the clay used was alluvium, but the deposit extends so far in all directions that most of it must be classed as a lake deposit. The former shore lines can be traced by beach ridges, one of which passes directly through Aitkin.

Several samples of the clays were taken. They slake at once and have only medium plasticity, requiring 22 per cent of water for molding. Their air shrinkage is 4 per cent; their average tensile strength is 150 pounds to the square inch; and they could be dried with artificial heat without checking. As burned at the Minnesota School of Mines experiment station at the university they gave the following results:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
05	Red	0.5	18
02	do	3.0	16
1	do	7.0	7
3	do	8.0	5
5	do	8.0	4
6	do	9.0	3

The clay becomes steel-hard at cone 03 (1,994° F.) and does not become viscous at cone 6 (2,282° F.), thus showing the very excellent range of vitrification of nearly 300°. Samples at different places from the east end of the deposits along Rice River to the exposures in the ditches near Aitkin show great uniformity. It should be safe to burn these clays thoroughly hard and perhaps to vitrification, though the presence of some organic matter makes it necessary to use care in oxidation during firing. So far they have been used only for common brick, but their great extent and easy accessibility make them worthy of further experiment. The fact that they are gray laminated clays but burn red indicates a high content of iron and low content of lime. Such a clay might originate by the leaching of lime from gray drift, or by a mixture of red and gray drift worked over by water.

East of Aitkin the red drift is more largely clay than at most other places. In a 25-foot exposure at the intersection of the Minneapolis, St. Paul & Sault Ste. Marie and Northern Pacific railways the clay is intensely red and contains very few pebbles, all of which could easily be removed by rolls. The clay slakes in two minutes and becomes highly plastic with 26 per cent of water. Its tensile strength is about 200 pounds to the square inch but is considerably reduced by rapid drying. Its air shrinkage is about 8 per cent. A burning test resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
06	Salmon	1	17
03	Red	2	15
1	.....do	8	3
3	.....do	8	2

The clay becomes thoroughly hard at cone 03 (1,994° F.) and reaches viscosity at cone 3 (2,174° F.), having a range of vitrification of nearly 200° F., with low porosity for several degrees before fusion. It resembles in nearly every way the material used with great success at Coon Creek, in Anoka County.

Similar clay is exposed at several places on the Cuyuna iron range and might be developed for building material at some of the growing towns. For example, in the northern part of Deerwood, near the shore of the lake, red drift comparatively free from pebbles has been exposed over a large area in grading the city streets. (See Crow Wing County, pp. 147–149.)

An irregularly laminated sandy clay south of the lake at the railway station at Deerwood may be partly glacial outwash but probably is partly a lake deposit. The Northern Pacific Railway spur to the iron mines cut through it for about 100 yards to a depth of 10 feet. Burning tests gave well-vitrified red brick, which were of best grade when the sandy and plastic layers were mixed and burned to a temperature about cone 1.

Lake and swamp clays that have accumulated at several places on the Cuyuna range make excellent common and hard-burned brick. No very large deposit has been explored, but the iron exploration has cut through bog deposits at the Rowe mine at Riverton on the so-called north range. Clay is reported in a swamp near the southeast corner of sec. 20, T. 46 N., R. 28 W. Several samples have been sent in by mine operators, and probably came from material that was 5being moved in stripping the ore at the mines. (See Crow Wing County.)

ANOKA COUNTY.

Clay-bearing formations:
- Recent: Lake clay.
- Pleistocene:
  - Gray laminated clay.
  - Red drift.
  - Gray drift.

At the south end of the panhandle of Anoka County, where it adjoins Minneapolis, there is a very extensive deposit of laminated gray clays that extends along both banks of the river well down

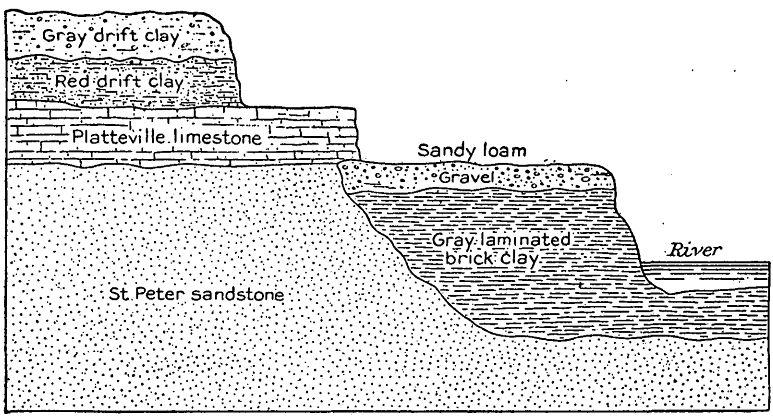


FIGURE 11.—Geologic section of the laminated clay in North Minneapolis. (After N. H. Winchell.)

into the city. The value of the land within the city limits, however, tends to crowd the brick industries northward into Anoka County. The detailed description of the clay of this vicinity is therefore given here rather than in the discussion of Hennepin County.

The bedrock formations along Mississippi River north of Minneapolis are the St. Peter sandstone and the overlying Platteville limestone. Above these the hillsides show first the red drift and over that the gray drift. Both the drift and the bedrock were evidently eroded by the glacial Mississippi River, a wide channel being thus formed in which the gray laminated clays were later deposited. (See fig. 11.) The entire mass of stratified clay undulates at angles of 10° to 20°. The clay is worked from top to bottom, having been opened to a depth of more than 30 feet at several brickyards. The curious internal structure (see Pl. XII) seems to have been caused by eddying motions in the periodic flood waters. A few concretions have been noted; one that was tested by the Minnesota Geological Survey was highly calcareous, containing 94.83 per cent of calcium carbonate. The sandiness of the deposit varies erratically, in some places being greatest at the top and in others at the bottom. Most of the pits opened are said to be pockety. Uniformity in the products manufactured is easily attained, however, by mixing clay from several parts of a fairly large exposure. A similar clay, probably of like origin, occurs in a less desirable situation in the southeastern part of Minneapolis.

The clay slakes at once and is highly plastic, requiring 24 per cent of water for molding. Its tensile strength is about 200 pounds to the square inch and its air shrinkage 3.7 per cent. The United States Bureau of Standards reports that it works well in the auger machine without much lamination. The following results of burning tests at the University of Minnesota agree closely with those of tests made by the Bureau of Standards:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
04	Cream	0	31
02	do	1	31
01	do	2	29
1	do	3	25
2	Buff	8	13
3	Greenish buff	13	4

The bricklets became hard at cone 01 (2,066° F.) and viscous at cone 3 (2,174° F.). The small range and sudden fusion of the clay make it difficult to burn the products to a low porosity. This clay is to be recommended for common brick and fireproofing.

Analyses of the clay at North Minneapolis have been made by F. F. Grout as follows:

Analyses of gray laminated clay of North Minneapolis.

Chemical analysis.

Silica	50.65
Alumina	10.25
Iron oxides	4.00
Magnesia	4.68
Lime	10.65
Soda	1.44
Potash	1.96
Ignition	14.40
Moisture	1.20
Titanium oxide	.52
	99.75

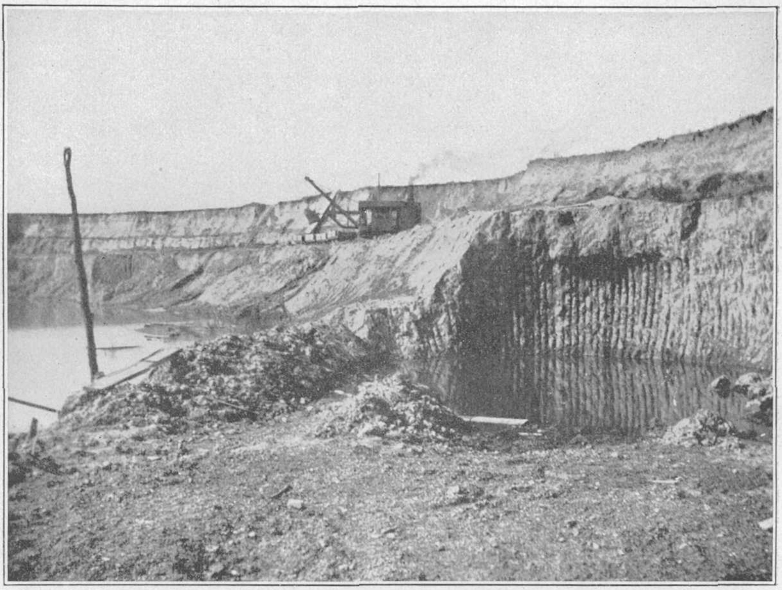
Mechanical analysis.

Fine clay	9.1
Coarse clay	10.9
Silt	79.5
Sand (total)	.5
	100.0

A.

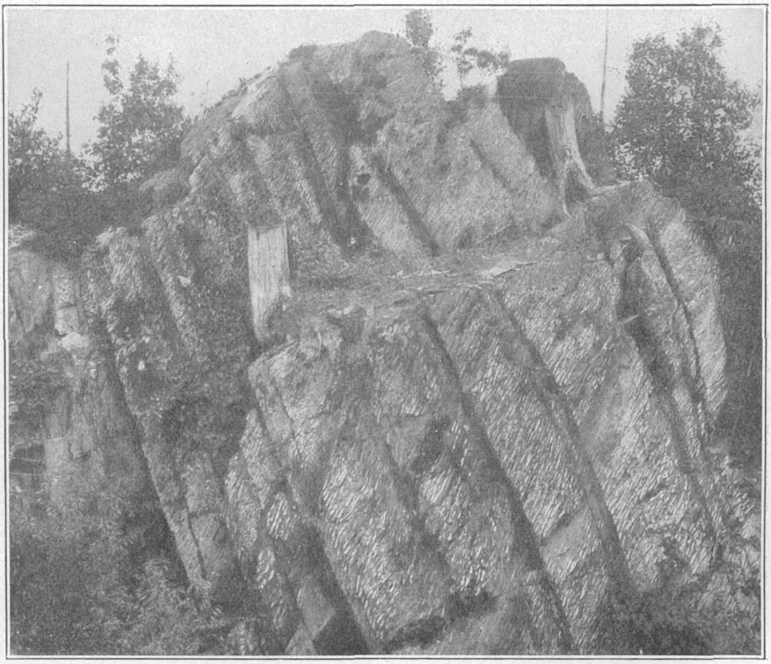
B.

VIEWS SHOWING EXAMPLES OF IRREGULARITY IN THE STRUCTURE OF LAMINATED CLAYS IN NORTH MINNEAPOLIS.



A. CLAY BANK AT COON CREEK.

Steam shovel at work on gray drift overburden; lower clay is red drift.



B. SLATE OF CARLTON COUNTY, SHOWING CLEAVAGE.

Work began on this clay in 1875, and since then eleven plants have been built and worked. Most of them produce cream-colored brick, for which there is considerable demand in the Twin Cities for backing brick walls and for interior work. At most of the plants the brick are not burned very hard, but they serve ordinary purposes well. Most of the plants have a capacity of approximately 40,000 brick a day and operate till the frost. Probably nine-tenths of the brick are burned in large scove kilns. To decrease costs of labor and fuel the Minneapolis Brick & Tile Co. installed a continuous kiln, with a gas producer, for firing at its plant on the west side of the river. Thus far the saving is not sufficient to recommend it in preference to the scove kilns operated by the same company on the east side of the river. Most of the plants at North Minneapolis have now been bought up by C. H. Klein, who owns the similar deposits at Chaska.

Hollow ware is produced by two companies. The Swanson Brick & Tile Co. has practically abandoned the production of common brick and devoted its energies to the production of hollow ware, with great success. The Minneapolis sawmills furnish a convenient supply of sawdust for mixing with the clay to render the finished product much lighter. The company now has a stock pile of sawdust and a thoroughly explored bank of clay sufficient to assure successful operation for many years. It has six oblong downdraft kilns and can turn out 40,000 brick a day. Work was begun at this plant in 1875.

The quality of the products made from this clay is indicated by the following results of tests. The Minneapolis building inspector reports that ten bricks from one plant showed an average crushing strength of 2,968 pounds to the square inch, a minimum of 1,600 pounds and a maximum (in a brick from the center of the kiln) of 5,080 pounds. Three other series of tests gave an average strength of 1,560 pounds to the square inch, a minimum of 631 pounds and a maximum of 2,770 pounds. Another series of five bricks from one plant had an average strength of 2,588 pounds. The general average of all the brick from the North Minneapolis deposits tested in this investigation is over 2,000 pounds. One test by the Minneapolis building inspector on a hollow tile about 4 by 8 by 17 inches, with six openings through it lengthwise, gave a strength of 604 pounds to the square inch.

The engineering department of the University of Minnesota reports that five dry bricks from North Minneapolis had an average crushing strength of 1,940 pounds to the square inch and that wet bricks were only slightly weaker. The modulus of rupture is 411, and the absorption 29.7 per cent. The product varies somewhat at different yards.

The Minnesota Paving Brick Co. (Hydraulic Press Brick Co.) formerly had an extensive plant at Coon Creek, but this plant is now closed. The red drift is 40 feet or more thick and has been explored over 200 acres. The overburden is 20 feet of gray drift. (See Pl. XIII, *A*.) As dug from the ground the red drift contains some pebbles and boulders, which necessitate treatment by rolls or grinding machinery, but these are not as numerous as in the average of the red drift throughout the State. None of the pebbles are limestone except in the overlying gray drift, which is discarded because it is not available without cleaning. At the plant all the red clay dug is put through a double series of conical rolls by which many of the pebbles are removed and the rest crushed to a size that renders them practically harmless. A sample of the clay that had passed through these rolls slaked promptly and showed fairly high plasticity, requiring 24 per cent of water for molding. Its shrinkage was 5 per cent and its tensile strength nearly 100 pounds to the square inch, though somewhat less if rapidly dried. The United States Bureau of Standards reports that the clay has fairly good vitrification behavior, its porosity being less than 5 per cent through a range of about 100° F. Enough organic matter is present to make the texture frothy and blebby if the clay is heated suddenly, but this is easily avoided by care at the plant. Burning tests resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
06	Salmon	2	17
05	do	3	16
03	Red	5	10
02	do	8	5
1	Brown	9	4

The following analyses were made by F. F. Grout on the clay as used at Coon Creek:

Analyses of red drift from Coon Creek.

Chemical analysis.

Silica	60.49
Alumina	12.62
Iron oxides	7.80
Magnesia	3.68
Lime	3.87
Soda	2.17
Potash	2.53
Titanium oxide	.42
Ignition	5.90
Moisture	1.94
	101.42

Mechanical analysis.

Fine clay	17.3
Coarse clay	24.6
Silt	47.5
Fine sand	5.1
Coarse sand	5.5
	100.0

The Coon Creek company had a steam shovel and six large oblong downdraft kilns with a total capacity of about 40,000 brick a day.

Its product was largely used by the Great Northern Railway in the construction of station buildings and paving station platforms. Some well-vitrified brick were roughened in imitation of klinker brick for fancy building material, and some were kept smooth for paving. At Minot a platform built partly with these brick and partly with the famous Purington brick from Galesburg, Ill., showed in practical service results very much in favor of the Coon Creek product. For harder use, as paving for city streets, the Coon Creek brick do not seem to have become as popular as they deserve. The city engineer of Minneapolis has tested them in comparison with the cobblestone paving produced in Minnesota and with the several types of paving brick now imported into the State. The average breaking load of Coon Creek brick was 16,000 pounds, the modulus of rupture was over 4,000 pounds, and the average crushing load was over 17,900 pounds, all three being greater than those of any other material

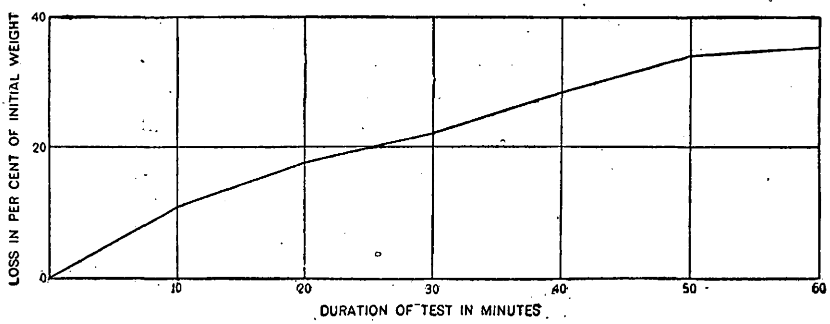


FIGURE 12.—Rattler test on paving brick from Coon Creek.

tested. The percentage of absorption was zero. The percentage of abrasion was 7.18, which was as low as that of the best imported paving brick, though higher than that of the granite of St. Cloud. A sample of vitrified brick from the Coon Creek plant was purchased in the open market and shipped to Edward Orton, jr., of Columbus, Ohio, to be tested as paving material. He reports, "The brick did very well, and I think full-sized pavers of the same quality would have easily met the requirements of the American Society for Testing Materials." The total loss after an hour in the rattler was 36.05 per cent. (See fig. 12.) The loss of the best grades of Illinois paving brick may be as low as 20 per cent on similar treatment; that of Iowa paving brick is 25 to 40 per cent.[1]

The high quality shown in all these tests indicates that the clays of the red drift of Minnesota are suitable for more extensive use. However, care must be used to select the less sandy deposits. (See Aitkin County, pp. 111–113.) At Elk River, only a short distance from the deposits just described, the material in numerous exposures

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[1] Tests of clay products: Iowa Geol. Survey Ann. Rept., vol. 14, p. 620, 1903.

has very different properties, though still burning red with a fair range of vitrification. The shrinkage of the sandy clays is very slight.

Clays of fair quality have accumulated in glacial and recent lakes in other parts of Anoka County. Such a deposit was developed about 25 years ago by P. P. Kelsey, 2½ miles north of Anoka, near the shores of Round Lake. At this locality smooth yellow clay covers many acres, but the deposit lies near the water level, and it would not be easy to get the products to the large markets. The clay slakes in three minutes and becomes highly plastic, requiring 32 per cent of water for molding. Its tensile strength is 150 pounds to the square inch and its air shrinkage 10 per cent. A burning test resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
06	Salmon	1	25
03	Buff	1	21
1	.....do	6	13
2	.....do	7	10
3	.....do	8	9
4	.....do	....	4

The bricklets became very hard after heating to cone 03 (1,994° F.), and reached viscosity at cone 4 (2,210° F.). Probably many of the lakes and swamps would reveal clays of this general character.

BECKER COUNTY.

Clay-bearing formations: Recent: Lake clay. Pleistocene: Gray drift.

Along the Minneapolis, St. Paul & Sault Ste. Marie Railway, about a mile south of the station at Detroit, is a massive deposit of gray drift that is full of pebbles and very sticky though not very plastic. The clay slakes in one minute and requires 30 per cent of water for molding. Its tensile strength is about 60 pounds to the square inch, even when rapidly dried. Its air shrinkage is 8 per cent. A burning test resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
04	Cream	3	28
03	.....do	3	25
01	Buff	5	20
2	.....do	13	3
3	Greenish buff	13	2
4	Green	....	....

The clay becomes hard after heating at cone 03 (1,994° F.), and is viscous above cone 3 (2,174° F.). 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 the loss of considerable money. Crushing and washing were tried to obviate the difficulty, but without success. Some of the gray drift in the vicinity contains much fewer pebbles, but none of it is entirely satisfactory.

Several swamps and lakes in the neighborhood of White Earth and Ogema contain clays that were used to make brick for the construction of the Government industrial school for the Indians and for St. Benedict's Mission. Very attractive and durable brick were made, though they show a few lime pebbles. If the market warrants it numerous deposits of such clay in this neighborhood will no doubt be developed.

BELTRAMI COUNTY.

Clay-bearing formations
- Recent: Lake and river clays.
- Pleistocene:
  - Silt of the Red River valley.
  - Gray drift.

The gray drift is thick over most of Beltrami 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. These silts increase in thickness toward the northwest. Both 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 the lake at the level of Mississippi River, contains blue and yellow clay of a common laminated type, which has been used at a medium-sized brickyard 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 sandy overburden. At the brickyard 1 to 8 feet of sand is being removed. Some sand is used in tempering the clay. An attempt has been made to mix the yellow clay, which is the chief body exposed, with the underlying blue clay. The blue clay appears to have been very plastic and was dug in a moist though solid condition, but it did not mix well and the brick were badly cracked, showing a most decided auger structure. Possibly more thorough mixing or the addition of sand would help. The two kinds of clay should be tried separately. It should be possible to make excellent products from this deposit. The average clay slakes promptly and the addition of 30 per cent of water develops a very high plasticity, which is easily reduced for better working by the addition of some of the sandy overburden. The air shrinkage of the clay is about 14 per cent, but with one part sand to two of clay this is reduced to 9 per cent, and the drying is much safer. The clay by itself develops cracks which reduce its strength, but the mixture of sand and clay has a strength of about 300 pounds to the square inch. Burning tests resulted as follows:

Clay alone.

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
03	Salmon buff	1	18
02	.....do	3	18
1	.....do	7	6
4	Red and yellow speckled	8	3

Two parts clay and one part sand.

06	Salmon	1	18
04	.....do	2	17
02	.....do	3	13
1	Red	4	3

The clay alone has the better range of vitrification (216° F.) and reaches viscosity at cone 4 (2,210° F.). The mixture of clay and sand has a range of 180° F. and reaches viscosity at a lower temperature (2,102° F.). A greater proportion of sand greatly decreases the range of vitrification and is therefore undesirable, but 20 to 30 per cent of sand improves the working qualities and is very desirable for brickmaking.

North of Bemidji the shores of Bemidji Lake consist of a more recent lake deposit which has been exposed by the gradual lowering of the lake level as its outlet has been eroded. The deposit is highly calcareous and was tested to ascertain whether it might be used for cement material. A partial analysis resulted as follows:

Partial analysis of calcareous clay from shores of Bemidji Lake.

	Per cent.
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 percentage of magnesia is too large. The material would probably burn to a cream-colored brick.

BENTON COUNTY.

Clay-bearing formations: Pleistocene:
- Gray laminated clays.
- Red drift.

The surface formation over most of Benton County is red glacial drift and glacial outwash, most of which is sandy. No clay pockets were noticed in it, but along Elk and Mississippi rivers are deposits of laminated clays, some of which may be of value. One was developed in a small way on a farm now owned by Mr. Harshman, at the crossing of the State road, over Elk River. Although it lies in an area of red drift the clay burns buff at high temperatures and has probably been transported by glacial streams from the area of gray drift farther north. It slakes at once and with 25 per cent of water becomes highly plastic. It shrinks 5 per cent on drying and develops a strength of about 150 pounds to the square inch, even when rapidly dried. A burning test resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
05	Pinkish buff	1	27
03	.....do	1	30
02	Buff	1	26
2	.....do	8	10
3	.....do	11	6

The clay is hard after burning at cone 02 (2,030° F.) and reaches viscosity at cone 4 (2,210° F.).

BIG STONE COUNTY.

In Big Stone County the only clays known are in the gray drift and are of the usual type, needing cleaning before use. Archean residual material is found at a depth of 250 feet in a well near Johnson.

BLUE EARTH COUNTY.

Clay-bearing formations:
- Recent:
  - River clays.
  - Lake and swamp clays.
- Pleistocene: Gray drift.
- Cretaceous: Shales and clays.

The Cretaceous clays seem to be widely distributed in Blue Earth County, but in most places they are deeply covered with gray drift of the common type. Exposures occur chiefly along the larger streams.

Five miles south of Mankato, in sec. 35, T. 108 N., R. 27 W., 30 to 40 feet of the Cretaceous overlies the Jordan sandstone and underlies 10 to 20 feet of drift along the banks of Le Sueur River. The Cretaceous outcrops are from a quarter to half a mile above the Red Jacket Bridge. The deposits are crumpled in complex fashion and the clay occurs in irregular lenses in beds of ferruginous sands and conglomerates, indicating that the whole series was probably distorted by the crowding of the glacial ice. Samples taken from some of the smaller clay lenses, rarely over 1 foot thick, that crop out for several hundred yards along the cliffs show very fine grained and chalky material, stained with iron in a few places. It does not slake when dropped into water. It is very lean, but it requires 27 per cent of water for molding. Its air shrinkage is about 1 per cent. It becomes steel-hard at about cone 3 (2,174° F.). It is highly

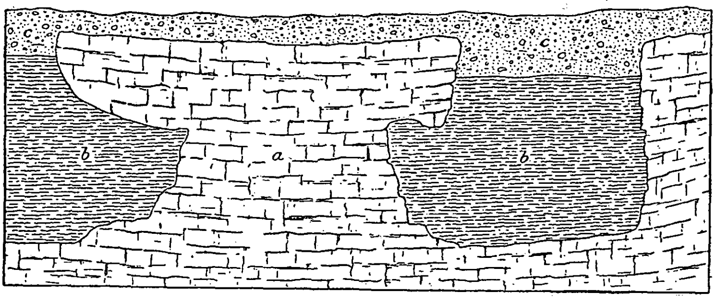


FIGURE 13.—Section of Cretaceous clay at South Bend. *a*, Shakopee dolomite; *b*, Cretaceous clay; *c*, drift. (After N. H. Winchell.)

refractory, and some samples will stand a temperature of cone 33 (3,254° F.) without deformation. In color the product ranges from buff to creamy brown. About 20 years ago the Pauline Pottery Co., of Chicago, tested the clay for use in the manufacture of fancy pot-

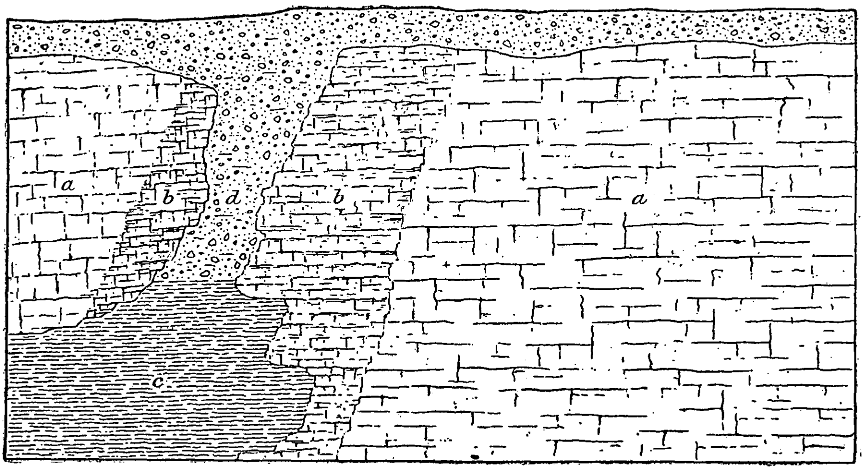


FIGURE 14.—Section of Cretaceous clay near railroad bridge, Mankato. *a*, Shakopee dolomite; *b*, weathered surface of same; *c*, Cretaceous clay; *d*, drift. (After N. H. Winchell.)

tery. Joseph Kern, of Mankato, who owns the property, has some beautiful but very fragile vases that were made in the experiment. A portion of the deposit, which appears concretionary, has 47.4 per cent silica and 14.5 per cent water and would be a valuable refractory clay if large amounts were available. Other outcrops near Mankato are considered to be Cretaceous shales.

Above the basal Cretaceous clays just described are a great many outcrops of alternating shale and sandstone and here and there one of ferruginous craggy conglomerate, which have been described by Upham.[1] Most of the clay beds are thin, and their extent is not well determined. (For analyses see p. 90.) Their physical character is indicated by a sample from Le Sueur County. (See pp. 187–191.) They are worthy of further exploration. (See figs. 13 and 14.)

The gray drift of most of the county shows the common characteristics. A sample was taken just southwest of Lake Crystal on the Chicago, St. Paul, Minneapolis & Omaha Railway, where the deposit, which is of considerable extent and 30 feet thick, contains less gravel than the average gray drift. After being crushed to 40-mesh, the clay was found to have low plasticity but to require 24 per cent of water for molding. Its tensile strength was more than 150 pounds to the square inch, even when rapidly dried. The air shrinkage was 4.5 per cent. Burning tests at the Minnesota School of Mines experiment station resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
04	Salmon	1	21
03	.....do	1	20
02	.....do	1	19
1	.....do	3	14
2	Brown	6	10
4	.....do	8	4

The particles of lime remaining in the burned brick up to the temperature of cone 03 (1,994° F.) cause its rapid distintegration on exposure to the air. The clay became too hard to scratch with a knife at this temperature and became viscous at cone 4 (2,210° F.).

Three plants were started to make use of the drift in this neighborhood, but none of them are now at work, though houses built 40 years ago of brick made here are in fairly good condition. Success would depend not only on favorable market conditions but also on the adoption of some method of removing limestone pebbles. A partial chemical test of some of the common clay in this county showed over 12 per cent calcium carbonate.

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

A deposit several feet thick extends over several acres on the farms of Joseph Kern and Frank Pearson, 5 miles southwest of Mankato. Near the surface the lime pebbles of the drift are fewer than in the average gray drift. The clay slakes in three minutes and is highly

[1] Upham, Warren, Minnesota Geol. and Nat. Hist. Survey Final Rept., vol. 1, pp. 432–439, 1884.

plastic, requiring 23 per cent of water for molding and showing a shrinkage of 5 per cent on drying. Its tensile strength is 100 pounds to the square inch but is seriously affected by rapid drying. A burning test resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
04	Salmon	1	15
03	.....do	1.5	14
01	Red	2	13
1	.....do	5	10
2	.....do	6	4
5	Brown		

The clay becomes steel hard at cone 03 (1,994° F.) and reaches viscosity at about cone 4 (2,210° F.). This deposit overlay one which was formerly worked for Cretaceous clay of refractory grade but which has been exhausted. It should yield a good grade of brick and tile, but whether it could be profitably worked depends on the economic conditions.

At Mapleton the whole neighborhood is covered with gray drift of the common type, containing the average number of pebbles.

Near Rapidan, along the Chicago, Milwaukee & St. Paul Railway, close to a bridge across Le Sueur River, an area of many acres is covered with gray drift whose upper part has been leached and furnishes somewhat better clay than the main body. The clay slakes in two 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 to the square inch, even when rapidly dried. As burned at the Minnesota School of Mines experiment station it gave the following results:

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

The clay becomes steel hard at cone 06 (1,886° F.) and viscous at cone 3 (2,174° F.). Although the lime pebbles are a serious defect it might be used without so extensive a treatment as is undertaken at Hutchinson. The market conditions are favorable, though fuel would have to be shipped in, and throughout the southern part of the State there is competition from the plants in Iowa.

Recent alluvium is found at many points along Minnesota River and some of its tributaries, such as the Le Sueur. A brickyard 2½ miles south of Mankato is in operation on 6 to 12 feet of workable alluvium which extends along Minnesota River in a flood plain of very great extent. It is typical of the material at many points between Chaska and New Ulm. An analysis is given in the report on Le Sueur County (pp. 187–191). 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 to the square inch, whether 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.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
05	Salmon	0	24
02	....do	1	22
1	Brown	7	10
3	....do	8	6
5	....do	9	3

The clay burns hard at cone 02 (2,030° F.) and is near viscosity at cone 5 (2,246° F.). The plant is making 4,000,000 common red brick of excellent quality each season by a soft-mud process.

Other favorable places for the development of this alluvium near Mankato are opposite Judson, about a mile up the river, and about 40 rods north of the city limits of Mankato, along the Chicago, St. Paul, Minneapolis & Omaha Railway, where the river basin has a width of 3 or 4 miles and the clay lies in a terrace at a somewhat higher level than at the present brickyard.

About 3 miles from St. Clair, on the south bank of Le Sueur River, a swamp of 40 acres or more has been drained by a ditch that exposes a clay deposit about 15 feet in thickness, the upper part of which is yellow and the lower part blue-gray. Peat of uneven thickness overlies the clay in part of the swamp. The clay is free from visible impurities. It slakes in six minutes and is very highly plastic, requiring 30 per cent of water for molding. Its tensile strength is about 80 pounds to the square inch and its air shrinkage 8 per cent. In burning it becomes hard and is salmon-colored at cone 06 (1,886° F.), at which its absorption is 16 per cent. It contains enough organic matter to cause it to swell and crack and develop black cores if rapidly heated, but if slowly heated and thoroughly oxidized it will yield good red brick and will not reach viscosity below cone 2 (2,138° F.). All conditions seem to be favorable for the manufacture of brick and tile, except that the deposit is about a mile from the railroad.

About half a mile south of Good Thunder station a swamp deposit covering many acres was worked for years up to 1904. The clay is almost 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. The following analysis was made by F. F. Grout for J. T. Schlesselman some years ago:

Analysis of surface clay of Blue Earth County.

Silica	70.29
Iron and aluminum oxides	18.71
Magnesia	1.35
Lime	2.02
Soda	.56
Potash	1.87
Moisture	2.15
Ignition	3.60

The clay is probably fairly characteristic of the bog deposits throughout much of Minnesota. It may contain some wind-blown loess, but it is made up largely of the wash from the neighboring hillsides. The humic waters of the bog have leached out the soluble lime and iron in some deposits but have left enough iron in most of them to make the clay burn red.

BROWN COUNTY.

Clay-bearing formations:
- Recent: Alluvium.
- Pleistocene: Gray drift.
- Cretaceous:
  - Shales.
  - Basal clays.
- Archean: Residual clay.

The only working plants in Brown County are at Springfield and New Ulm. The Springfield plant is supplied from an extensive bed of laminated Cretaceous shale and the New Ulm plant uses the extensive brown and yellow alluvial clays along Minnesota River. Most of the gray drift in this county contains many pebbles, chiefly of limestone, and as clays of much better quality exist in the county the plants which have used the drift have been abandoned and no further development of it is to be recommended.

New Ulm.—The abundance of Cretaceous outcrops in the immediate vicinity of New Ulm has led to several investigations. The best clays now available in quantity are a few miles up Cottonwood River, out of convenient reach of shipping facilities. However, some of the shales near the town have not been thoroughly explored. The Cretaceous beds are subject to change within short distances, and good clays may lie in many places between outcrops that are sandy or that contain thin limestones.

Red, yellow, and blue clay is exposed in a road cut in park property on the north side of North German Park, close to the New Ulm Farmers' Elevator. Most of the clay probably lies under the park, though it might also be traced both east and west along the hill. A boring said to have been made some years ago found 26 feet of blue clay below that now exposed. (See fig. 15.) No impurities are visible. The sample slakes at once. With 28 per cent of water, the clay is highly plastic. It shrinks 8 per cent on drying and has some tendency to crack, but if care is used it develops a strength of nearly 100 pounds to the square inch. A burning test resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
06	Salmon	0	21
04	....do	1	19
02	Buff	2	17
1	Greenish gray	4	11
2	....do	....	....

The clay is hard after burning to cone 06 (1,886° F.) and reaches viscosity at cone 2 (2,138° F.). Its decrease in porosity seems to be

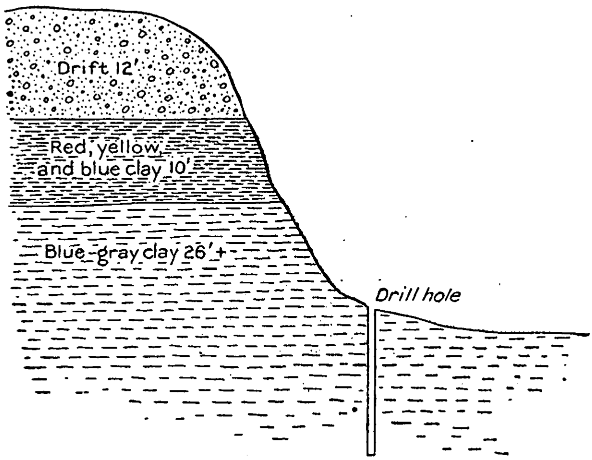


FIGURE 15.—Section of Cretaceous shale at Farmers' Elevator, New Ulm.

gradual, and it should make well-vitrified brick. It compares favorably with the clay now used at Springfield.

In the southeastern part of New Ulm a pottery that was established about 30 years ago obtained its material from a bed 4 to 8 feet thick whose extent is uncertain but which is said to underlie the central part of the town beneath not more than 10 to 12 feet of overburden. The clay slakes in two minutes, is highly plastic, and requires 20 per cent of water for molding. It has a tensile strength of 200 pounds to the square inch and can safely be dried with artificial heat. Its air shrinkage is less than 4 per cent. As burned by the Minnesota School of Mines experiment station, it gave the following results:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
05	Cream	0.7	14
03	Buff	1.0	13
1	.....do	1.4	12
5	.....do	2.5	11
12	Light gray	....	10

The clay becomes hard at cone 03 (1,994° F.) and, though well vitrified, does not seem to be near viscosity at cone 12. The extent of this deposit should be carefully studied.

A much less favorably situated outcrop occurs near the plant of the A. Schell Brewing Co. Thin layers of limestone, which occur in the outcrop and can not easily be separated from the clay, ruin the products burned from this clay at any temperature.

Near the south side of New Ulm, at the Chicago & Northwestern Railway crossing over Cottonwood River, shales are exposed to a depth of 40 feet. The extent of the formation is unknown but is probably very great. Its lower main part is a rather soft gray clay, very favorably situated for development. It slakes very slowly and is highly plastic, requiring 29 per cent of water for molding. Its tensile strength is 200 pounds to the square inch but is considerably injured by rapid drying. 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.	Shrinkage.	Absorption.
		Per cent.	*Per cent*
05	Salmon	2	12
02	.....do	4	7
01	Brown	5	3
2	.....do	5	2

The clay becomes hard at cone 05 (1,922° F.) and viscous above cone 2 (2,138° F.). The porosity decreases gradually. Most of the clay is gray, and clay of similar appearance can be traced through the neighboring hills. Borings and wells reveal the fact that it extends over considerable territory beneath later deposits.

The upper portion of the deposit is red, sandy, and evidently calcareous and possibly contains some gray drift and Cretaceous limestone. It is certainly much less valuable clay than the lower part, but it is thin, and there is 40 feet of the gray clay below.

The extent of plastic Cretaceous clay is shown by a similar deposit of even better quality that crops out along Cottonwood River in sec. 31, T. 110 N., R. 30 W., 2 miles west of New Ulm. The drift cover is heavy, and the outcrop shows less than 10 feet of clay in a vertical bank, but the deposit is known by wells and other excavations to be 16 to 20 feet thick and to underlie probably 300 acres. In the high bluffs and hills the clay has a heavy overburden of drift and in some places an additional overburden of sandy Cretaceous deposits; but along the river flat these have been mostly eroded away and only 4 to 16 feet of river wash remains above the clay. (See fig. 16.) Samples from the deposit on the farm of William Alwin and

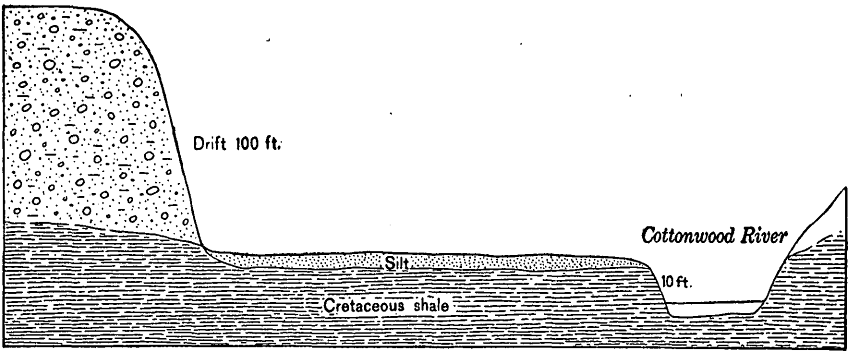


FIGURE 16.—Section of Cretaceous shale on Cottonwood River, Brown County.

from the outcrop in the river bank show the same physical character. The shale slakes in three minutes and with 30 per cent of water is highly plastic, working well in an auger machine. Its air shrinkage is 10 per cent, and if carefully dried it has a tensile strength of over 200 pounds to the square inch. Care is needed to prevent checking during the drying process. Several burning tests resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
010	Salmon	1	14
07	.....do	2	12
04	Red	4	10
1	.....do	5	7
2	.....do	5	7
3	.....do	5	6
5	.....do		11

The clay becomes hard after burning to cone 010 (1,742° F.) and reaches viscosity at about cone 4 (2,210° F.), having thus a range of vitrification of 478° F.—as good as that of several clays now used. The porosity decreases slowly and, though never low, is entirely satisfactory for vitrified products. The presence of some organic matter and of the iron which makes the clay burn red necessitates a little care in oxidation during firing but with slow burning causes no trouble. All the conditions are favorable except that the material is not easily shipped. A 2-mile spur up the river would be the most convenient method of obtaining connection with the railroads.

A sample of gray shale from the south bank of Cottonwood River in this immediate neighborhood, in sec. 31, T. 110 N., R. 30 W., was sent by John Lind many years ago to the United States Geological Survey and was analyzed by T. M. Chatard, with the following results:[1]

Analysis of gray Cretaceous shale from Cottonwood River.

Silica	61.32
Alumina	12.27
Ferric oxide	3.62
Ferrous oxide	4.18
Magnesia	1.76
Lime	.99
Soda	.42
Potash	3.59
Ignition	10.73
Titanium oxide	.66
Barium oxide	.05
Phosphorus oxide	.27
Sulphur trioxide	.19
Manganous oxide	.27
	100.32

Within a mile west of these deposits, in sec. 36, T. 110 N., R. 31 W., are other Cretaceous outcrops of slightly different character. The

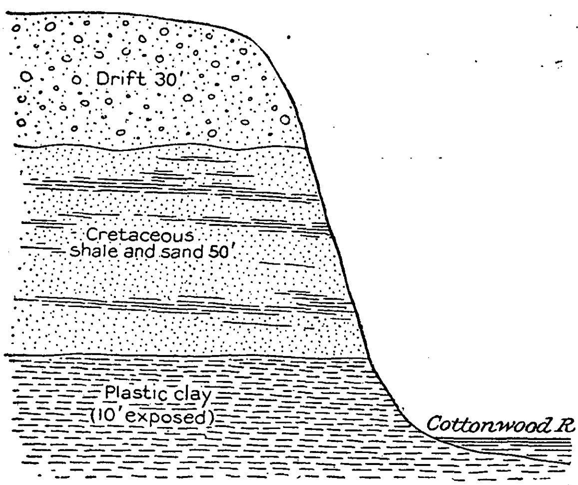


FIGURE 17.—Geologic section on Cottonwood River, Brown County, showing Cretaceous deposits and drift.

relations, as seen on J. Seifert's farm, are shown in figure 17. Mining would be difficult on account of the soft sandy overburden. The

[1] U. S. Geol. Survey Bull. 60, p. 151, 1890.

clay at water level is somewhat variable in color and texture. The plastic masses are mostly red and white and will all pass a 60-mesh sieve. A little farther up the river the creamy-white clays are gritty and only about 50 per cent will pass a 60-mesh sieve. Samples from the largest exposure were tested by the Bureau of Standards. The clay slakes in three minutes and requires only 19 per cent of water for molding. Its shrinkage on drying is 5 per cent. Machine-molded bricks are inclined to crack, but that is not true of hand-molded bricks. In burning, the colors are light pink to buff, with a tendency to flash at higher temperatures. At cone 06 (1,886° F.) the clays burn too hard to be scratched with a knife, have a very small shrinkage, and an absorption of 15 per cent. They are highly refractory, maintaining their shape to cone 31½ (3,200° F.), with only a small shrinkage and a gradual decrease in absorption. Mr. Aufderheide has used this clay in the brickyard at New Ulm and has made some fire brick, which stand furnace temperatures very well but which do not show satisfactory strength after being repeatedly heated and cooled. No other attempts have been made to use these clays. It should be possible, by washing, to remove the grit and some ferruginous grains and produce a kaolin of good color.

At some of the outcrops in sec. 36 the gritty nature of the clay and its massive, nonstratified structure strongly suggest that it is residual from the Archean granite gneisses rather than a Cretaceous sediment. The geologic relations are not clearly shown, but a study of the region shows that such residual clays are not improbable.

River clay is known to exist to depths of 8 or 9 feet over several acres 1½ miles southeast of the center of New Ulm. The upper part of the deposit is dark brown and the lower part yellow and more plastic. The only overburden is the sod, and the impurities are, as usual in river clays, scattered patches of sand, a few boulders, and some organic matter. The deposit is favorably situated and, since 1875, has been used in making red brick in a soft-mud machine with a capacity of two or three million brick in a season.

Three or four miles south of the Chicago & Northwestern Railway at Essig clay crops out along Cottonwood River almost continuously for a mile, rising 6 feet above water level and extending to an unknown depth below. It is white to gray and very plastic. The outcrops are not perfectly continuous, and there seems to be a difference between the white clay and the gray clay which is associated with it. It may be that the white clay exists mostly in pockets. Both the white and the gray clay slake in a few minutes and are highly plastic, requiring 23 per cent of water for molding. Their tensile strength is well above 100 pounds to the square inch, even after rapid drying. Their air shrinkage is about 7 per cent. As burned by the Minnesota School of Mines experiment station they have the following character:

White clay.

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
010	Buff	0	15
06	.....do	1	14
01	.....do	4	8
2	.....do	5	6
3	.....do	5	5
5	.....do	6	4
10	Gray	....	4

Gray clay.

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
010	Salmon	0	15
06	.....do	1	13
03	.....do	3	8
2	.....do	4	6
3	.....do	5	6

At all the specified temperatures the brick made from the white clay are hard and undeformed. The absorption changes indicate the progress of vitrification through nearly 700° F., and the clay will evidently stand a high temperature without becoming viscous.

The gray clay likewise becomes hard but not viscous at the temperatures reported, but it evidently contains enough organic matter to cause danger of the formation of black cores. In a rapid heat the brick swelled and cracked at cone 3. Both of the clays, however, show an excellent range of vitrification and should be utilized if transportation facilities can be provided. The white clay has been tested by the Red Wing Stoneware Co. with results that are said to be favorable, but the material has not been used because it is not very easily accessible. The overburden is not a serious handicap, for the clay crops out in a great many places.

Springfield.—Just east of Springfield, about 30 miles up Cottonwood River from New Ulm, the A. C. Ochs Brick & Tile Co. has developed a large patch of Cretaceous clays along the Chicago & Northwestern Railway. The clay is 20 feet thick above water level and is known to extend over 20 acres. It is gray and thin bedded and contains both pyrite and limonite in concretionary masses an inch or two thick. Over most of its area it is covered with common gray drift and is somewhat variable in sandiness. The clay slakes in two minutes, is highly plastic, and requires 29 per cent of water for molding. Its tensile strength is 200 pounds to the square inch but is much reduced if rapidly dried. Its shrinkage on drying is about 8 per cent. As tested by the Bureau of Standards a sample selected as especially rich plastic shale showed serious auger lamination and much danger of cracking on drying. The clay burns buff and pink at low temperatures and chocolate color when vitrified. The range of vitrification is excellent (400° F.). The porosity decreases gradually and is less than 1 per cent for over 100° F. without reaching viscosity. Burning tests at the University of Minnesota resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
010	Buff	3	16
07	Salmon	4	12
05	....do	5	10
03	....do	8	5
1	Brown	9	1
2	....do	10	1

The bricklets tested were too hard to be scratched with a knife at all these temperatures, but they retained their form perfectly. The clay is available for vitrified brick and tile and probably for roofing tile also, if warping can be prevented in drying. A special die might be successful. For analysis of the clay see page 91.

A. C. Ochs has been operating on this clay for 20 years and has manufactured mostly hollow brick and tile, in eight kilns which, when full, contain about 4,000,000 brick. It is planned to use a steam shovel hereafter in working the bank. Both soft-mud and stiff-mud brick are manufactured, and the strength of the product is excellent.

The Minneapolis building inspector found that three well-burned building tile of 91-inch cross section, with two horizontal holes, has an average compressive strength of 965 pounds to the square inch.

The degree of vitrification easily obtained would indicate that the material is suitable for paving brick, but no attempts are now made to produce pavers. Nearly all the vitrified brick are made hollow, to facilitate drying and to make them lighter in weight and reduce shipping charges. Such hollow brick show a resistance to abrasion which, though not such as a paver requires, is encouraging. If the mechanical troubles involved in drying and burning larger blocks without holes can be overcome, the brick will probably stand a good rattler test.

West of Springfield are other outcrops of Cretaceous shales. A shaft sunk here in exploration for coal many years ago passed through a thick series of shale beds, a few of which contained enough organic matter to produce dark colors but not enough to interfere with their use as clay. The banks of Cottonwood River and its tributary gulches have exposed similar shale. Mr. Ochs has recently built a tile plant west of Springfield, adding to his work of making brick. All the samples taken required a little more heat for vitrification than the clay east of Springfield, and all showed a good range of vitrification, which may be taken as favorable indications. All the clays slake in a few minutes and become highly plastic with about 31 per cent of water. Their tensile strength is 200 pounds to the square inch, and they can be dried much more rapidly than the clay at the brickyard east of Springfield. The shrinkage on drying is 8 per cent. Burning tests resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
06	Buff	1	20
03	Salmon	5	12
01	....do	7	8
1	Red	8	6
3	....do	9	4
5	Brown	9	4
6	....do	....	12

The clay is hard after heating to cone 04 (1,958° F.), and reaches viscosity at about cone 5 (2,246° F.), with a low porosity over a considerable range. The temperature of viscosity is rather low for sewer-pipe clay, but the range of vitrification is excellent. On passing the point of fusion the clay swells and becomes blebby. Analyses of the clay by F. F. Grout are as follows:

Analyses of Cretaceous shales from deposits west of Springfield.

Chemical analysis.

Silica	63.65
Alumina	17.27
Iron oxides	4.75
Magnesia	1.21
Lime	.06
Soda	.91
Potash	2.47
Ignition	7.36
Moisture	2.03
Titanium oxide	.62
	100.33

Mechanical analysis.

Fine clay	25.5
Coarse clay	14.0
Silt	58.6
Fine sand	1.4
Coarse sand	.5
	100.0

The Cretaceous clays of Brown County vary in properties, but some of them are very promising, and well records indicate that they are present throughout most of the southern part of the county and in some places are 200 feet in thickness.

CARLTON COUNTY.

Clay-bearing formations:
- Recent: Alluvium.
- Pleistocene:
  - Gray laminated clay.
  - Red clay of Lake Duluth.
  - Red drift.
- Huronian: Slates.

A very extensive brick industry has been developed at Wrenshall, in Carlton County, where gray laminated clays occur in immense quantities. The existing brick plants are within a short distance of the station, but similar clay lies along the railroad half a mile farther north and for some distance farther east. Other clays in the county have not been much developed, though an attempt was made to use the slate at Thomson, which is capable of yielding fancy products.

Along St. Louis River from Cloquet to Carlton Huronian slates crop out in especially favorable position in glaciated knobs, projecting above the general level of the drift. These slates are not now used, and attempts to use them in the past do not appear to have been very successful, though details are not available. The slate is metamorphosed and has developed good secondary cleavage (see Pl. XIII, *B*), though it is not very satisfactory as roofing material. The variation from a graywacke to a slate is irregular, and the folding and crumpling of the formation make it difficult to predict exactly where good slates are available; but during a hurried trip over the district many convenient places were seen 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 nonplastic and has very little tensile strength and no air shrinkage. The crushed material requires only 9 per cent of water for molding. At cone 5 (2,246° F.) it is thoroughly vitrified and dark red. The superintendent of the St. Louis River Slate Brick Co., organized in 1892, had a patent or secret process which he tried out with considerable thoroughness, but nothing has been done for the last 20 years. The product was red pressed brick of excellent quality. They were used in several Duluth buildings that are still standing. One disadvantage of the brick was their high specific gravity, which increased the freight rate per thousand brick.

Fancy brick could readily be made from this slate by the addition of some of the more easily fusible drift clays of the neighborhood. Laboratory tests indicate that the clay of Wrenshall, which occurs in so great quantity a few miles east, or, even better, the red bouldery clay that is widely distributed in the region around the west end of Lake Superior, would be excellent for bonding clay. With 5 per cent of red clay the mixture becomes so hard at cone 06 (1,900° F.) that it can not be scratched with a knife, and at cone 5 (2,250° F.) it is still undeformed. The color ranges from light to dark red between these temperatures, and the appearance changes from that of common red brick to that of a thoroughly vitrified klinker brick. Brick made from a mixture of these clays with slate crushed to lumps a quarter of an inch or less in diameter closely imitated the popular rough appearance of klinker brick. 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 the rough lumpy brick may be given a glazed appearance, and the excellent quality of the resulting product seems to promise well for this deposit.

Deposits around the west end of Lake Superior make it certain that during the retreat of the ice front the Lake Superior basin was dammed, so that water was raised 500 to 700 feet above the present lake. In this lake, known as Lake Duluth, which extended far out into Carlton County, the melting ice dropped red-drift clays and gravel, and into it glacial rivers brought various sediments. Water sorting formed laminated clays, to which floating ice contributed some boulders. Streams from the gray-drift areas to the west produced gray clays. The ice itself brought red bouldery clays.

The red bouldery clays have thus far been little used in Minnesota but are worthy of more attention both as fusible slips and as plastic binders for lean clays near by. In Carlton County they are at least 60 feet in thickness and many miles in extent. The southernmost of the accessible outcrops is 4 miles east of Moose Lake, on the Minneapolis, St. Paul & Sault Ste. Marie Railway. Occurrences at Holyoke are especially favorable, and there is an interesting deposit within 2 miles of Wrenshall, where the gray laminated clays are also well represented. The deposit is no doubt continuous between all these localities. Characteristically the clay lacks the pronounced lamination and sandy layers of most red glacial lake and river clays. The chief distinction between it and common pebbly red deposits of the northeastern drift is its greater content of clay and its faint stratification. It is found on all sides of the western part of Lake Superior basin, where a deposit having a glacio-lacustrine origin would be expected. As stated above (p. 97) Mr. Leverett regards this clay not as a strictly lacustrine deposit but as composing a glacial moraine deposited in a lake.

The clay slakes in two minutes and shows a very high plasticity, requiring 27 per cent of water for molding. Its tensile strength is nearly 100 pounds to the square inch, but it cracks rather seriously if rapidly dried. Its air shrinkage is 9 per cent. A sample taken near Holyoke gave the following results in a burning test:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
010	Red	1	16
06	do	3	10
02	do	8	2
2	do	9	1

The clay is hard after burning to any of the specified temperatures and reaches viscosity at about cone 1 (2,102° F.). Rapid heating causes black cores and consequent swelling. Oxidation is a little slow on account of the fineness and density of the clay. These points can easily be cared for in burning. The low fusing temperature of the clay and its fineness make it desirable as a slip glaze for brown semi-refractory ware. This clay mixed with the Huronian slate, as mentioned above, could be used for making fancy brick.

On account of its very high plasticity and shrinkage the clay was tested after being mixed with sand, which is abundant in the neighborhood. For common or vitrified brick the addition of sand improved the clay both in working and shrinkage. With 50 to 75 per cent of added sand the range of vitrification is still high enough to be satisfactory and the temperature of viscosity is somewhat raised—to about cone 4 (2,210° F.).

The following analysis of clay of this type from Carlton County was made by A. W. Gauger. (See also Cook County, pp. 145–146.)

Analysis of red clay of Lake Duluth.

Silica	50.51
Alumina	15.89
Iron oxides	8.21
Magnesia	5.14
Lime	7.10
Soda	1.66
Potash	1.87
Moisture	2.44
Loss on ignition	7.35
Titanium oxide	.26
	100.43

The gray laminated clays washed into Lake Duluth from the west contain few boulders. They are most abundant in the vicinity of Wrenshall, where five large, successful plants have been in operation, each utilizing essentially the same type of clay, which has been developed to a depth of about 50 feet and explored to a depth of 80 feet. In the uppermost few feet the clay is more or less disturbed and mingled with pebbles, but this condition gradually disappears with increasing depth and the stratification becomes very regular. Gentle undulations such as are seen in the laminated clay north of Minneapolis (see p. 114) occur here also. (See Pl. I, p. 20.) The blue and gray parts of the clay burn cream-colored; but the top part of the deposit, which has not only been disturbed physically but has apparently been chemically altered by leaching, is red and burns red. In the upper 10 to 15 feet the disseminated lime has apparently been segregated into concretions, which, however, are in few places abundant enough to be a serious handicap. The clay extends generally under the flat region and is seen along the sides of many deeply cut ravines draining into St. Louis River. It extends up the slope about 300 feet above the flat on which Superior and West Duluth are built. The detailed structure of the clay is similar to that of clays along Minnesota and Mississippi rivers, but its occurrence in a lake basin in a place where no river could have flowed, as well as its wide extent, indicate that it is a lake deposit rather than river silt.

The clay slakes in three minutes and shows fairly high plasticity, requiring 23 per cent of water for molding. Its air shrinkage is 4 per cent and its tensile strength 175 pounds to the square inch, even when rapidly dried.

Tests by the Bureau of Standards show that it burns buff at low temperatures but becomes greenish yellow when well vitrified. It has a short range of vitrification, the porosity dropping from 42 per cent to nearly zero in about 100°. It is not safe to try to vitrify this type of clay, but it makes excellent common brick. An analysis by A. W. Gauger is as follows:

Analysis of clay from Wrenshall.

Silica	48.79
Alumina	12.08
Iron oxides	4.60
Magnesia	5.54
Lime	12.10
Soda	2.22
Potash	2.05
Loss on ignition	12.02
Moisture	1.26
Titanium oxide	.29
	100.95

The plants have capacities of 40,000 to 140,000 brick a day. Some of them find the soft-mud process more favorable, but most of them use stiff-mud machines. Very little hollow ware is produced. Red brick are obtained only when the upper layers of clay are used separately. If clay from the whole deposit is used in proportion as it is exposed, the one-fourth of red-burning clay is not sufficient to affect the color of the three-fourths of cream-burning clay. The quality of the products as tested by the experimental engineering department of the University of Minnesota is as follows:

Results of tests of Wrenshall brick.

Nature of brick.	Crushing strength (pounds per square inch).		Modulus of rupture.	Absorption (per cent).
	Wet.	Dry.		
Soft-mud, cream	2,809	2,166	982	29.4
Stiff-mud, cream	2,834	4,762	926	21.7
Stiff-mud, sewer	4,474	5,888	1,409	18.5
Soft-mud, red	3,354	3,233	679	14.9
Stiff-mud, red	3,770	5,247	1,189	13.3

Red drift of the common pebbly character just north of Barnum was used some years ago for red brick. The whole region around Barnum seems to consist of pebbly clay, and the pebbles must be crushed before the clays will make satisfactory products. The clay slakes in five minutes and has fairly high plasticity, requiring 21 per cent of water for molding. Its air shrinkage is over 6 per cent and its tensile strength about 75 pounds to the square inch. Burning tests at the Minnesota School of Mines experiment station resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
05	Red	2	11
02	do	7	6
5	do		

The clay becomes hard at cone 04 (1,958° F.) and seems to contain enough organic matter to develop black cores and to swell greatly if rapidly heated; but if thoroughly oxidized it will stand a temperature of about cone 2 (2,138° F.). Clay of this type is widespread throughout the eastern part of the State.

Alluvium has been deposited along St. Louis River in the few places at which there are flood plains. At the place where Cloquet stood before the fire of 1918 the river flows through an extensive flat. Before the lumber yards extended over most of the flat a small brickyard produced some red soft-mud brick of fair quality, which were used in buildings at Cloquet. The silt from the northeast side of the river was sampled to determine its quality. It slakes at once and has low plasticity, requiring 21 per cent of water for molding. Its air shrinkage is 3½ per cent, and its tensile strength is over 100 pounds to the square inch, even when rapidly dried. On being burned it gave the following results:

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

The clay becomes hard at cone 02 (2,030° F.) and reaches viscosity a little above cone 4 (2,210° F.). It should burn to an excellent hard red brick.

CARVER COUNTY.

Clay-bearing formations:
- Recent: Alluvium.
- Pleistocene:
  - Gray laminated clays.
  - Gray drift.

The only place in Carver County where brick is being manufactured is at Chaska, on Minnesota River. Gray laminated river clays of the glacial River Warren, which was the outlet of Lake Agassiz, are used; and the gray drift and alluvium are not exploited in competition with this larger and better deposit.

The section at the clay pit consists of 20 to 40 feet of partly stratified sand and gravel, underlain by 100 to 200 feet of dark-gray clay. These beds extend under the river valley for hundreds of acres. The laminated character of the clay shows that it was deposited when the river was greatly swollen by the melting of glacial ice. When the stream was rapid, sand was irregularly mixed with the clay and is now found as pockets, "wells," and streaks. These, however, are so scattered that by mixing material from different parts of the bank a uniform quality of brick can 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 somewhat variable, one briquet showing 200 pounds to the square inch and even the sandy layers yielding some strong briquets. Two pieces of clay when pressed together had almost no adhesion, showing, if the test is reliable, that defective auger structure may be developed. The average clay shows a shrinkage of 7.5 per cent on drying, but admixture of some of the particularly sandy layers reduced this to 4.5 per cent, apparently without injuring the product. The clay burns buff up to the temperature of viscosity and can be burned hard with very little shrinkage. Its absorption is over 20 per cent, even in well-burned brick as found on the market, but laboratory tests show that this may be reduced before reaching the melting point. The clay became hard at cone 02 (2,030° F.) and viscous at cone 4 (2,210° F.); and a half-and-half mixture with material from the particularly sandy layers gave very similar results. Four plants using this clay are in successful operation, employing over 300 men. All are under one management and use essentially the same method, having permanent oblong updraft kilns. Their aggregate capacity varies from 45,000 to 140,000 brick a day; in a recent year they produced 50,000,000 brick. Coal is the only fuel available. A large proportion of the product is 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 are provided with steam shovels for digging the clay. Of some products from Chaska tested by the Minneapolis building inspector two sewer brick showed a crushing strength of 4,250 pounds to the square inch; four miscellaneous brick in one set gave an average strength of 1,600 pounds; a set of 14 bricks, probably selected with some care (though this was not stated), had an average crushing strength of 2,635 pounds; two hollow bricks had a strength of 236 pounds; and one hollow tile with three horizontal openings had a strength of 158 pounds to the square inch.

The experimental engineering department of the University of Minnesota found that five soft-mud well-burned Chaska brick, tested dry, had an average crushing strength of 2,081 pounds to the square inch, a modulus of rupture of 658 pounds to the square inch, and an absorption of 22.2 per cent. Hollow building blocks had an average strength of 505 pounds to the square inch, a modulus of rupture of 600 pounds, and an absorption of 10 per cent. The wet brick had about the same strength as the dry.

CASS COUNTY.

Clay-bearing formations:
- Recent: Lake clays.
- Pleistocene:
  - Gray drift.
  - Red drift.

Cass County is covered with gray drift and outwash, except in its two southeastern corners, where red drift is exposed. Lake clays of value may be discovered near White City. The clays of the gray drift would require cleaning before use.

CHIPPEWA COUNTY.

Clay-bearing formations.
- Recent: Alluvium.
- Pleistocene:
  - Gray laminated clay.
  - Gray drift.
- Archean: Residual clay.

Throughout Chippewa County the gray drift is abundant and is rarely free from pebbles. At Montevideo it was abandoned for river clays, which were in turn abandoned. Considerable clay is visible in the flat near the mouth of Chippewa River. Opposite Minnesota Falls and also at Tunsberg[1] are small outcrops of granitic residual clays that are not likely to be of much value. Meinzer[2] reports well records showing 70 feet of white Cretaceous and Archean clays at Montevideo at a depth of several hundred feet.

A railroad cut opposite Granite Falls was deep enough to expose unweathered gray drift below the yellow. Both the yellow and gray drift contain numerous limestone and other pebbles and about the same proportion of sand as the gray drift used at Hutchinson to make draintile. The clays slake in 2 minutes and are highly plastic, requiring 17 per cent of water for molding. Their tensile strength is about 150 pounds to the square inch, and their shrinkage on drying is less than 4 per cent. These clays require a temperature for vitrification somewhat above the average. The yellow and gray clays are essentially similar.

About 5 miles northeast of Appleton and a mile east of the Great Northern Railway a well reveals a plastic blue clay which is apparently of the laminated type. It slakes at 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 more than 150 pounds to the square inch but is greatly reduced by rapid drying. When tested at the University of Minnesota this clay proved to be of very poor quality. The brick burn salmon-colored and show very little shrinkage up to the temperature of cone 02 (2,030° F.), where they had an absorption of 28 per cent. By raising the temperature 40° the shrinkage increased to 16 per cent, the absorption decreased to 2 per cent, and the clay became viscous. It is certainly not safe to burn this clay hard.

CHISAGO COUNTY.

Clay-bearing formations:
- Pleistocene:
  - Red laminated clay.
  - Gray drift.
  - Red drift.
- Cambrian.

At Rush City red brick were made from till for several years. A particularly good clay, apparently glacial outwash, was developed 1½ miles south of the town. It may have been derived from the ice sheet that brought the gray drift, but it contains enough ferruginous material from the northeast to make it burn red, and it is here classed with the red drift. The workable clay is more than 8 feet thick. It

[1] Winchell, N. H., Geology of Minnesota: Minnesota Geol. and Nat. Hist. Survey Final Rept., vol. 2, p. 211, 1888.

[2] Meinzer, O. E., U. S. Geol. Survey Water-Supply Paper 256, p. 153, 1911.

slakes at once and is highly plastic, requiring 27 per cent of water for molding. Its tensile strength is between 50 and 75 pounds to the square inch, and its air shrinkage between 5 and 6 per cent. Burning tests resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
06	Salmon	0	20
05	do	0	18
01	Red	5	10
3	do	7	6
4	do	9	2
5	do		

The clay becomes too hard to be scratched with a knife at cone 05 (1,922° F.) and begins to be viscous at cone 5 (2,246° F.). It has thus a range of vitrification of over 300° and should burn to a very hard, excellent product. Brick were made here for several years and were shipped over a spur track to the Northern Pacific Railway, half a mile away. It is said that the work was abandoned on account of the difficulty in getting labor, but if the clay is as excellent as it appears it should warrant exploitation under favorable conditions.

Hills of gray drift cover much of Chisago County. A sample of clay taken at Center City from an exposure 40 feet thick slakes in two 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 to the square inch. This clay has 33 per cent sand and 7 per cent lime, as against 30 per cent sand and 9 per cent lime in the material profitably used at Hutchinson. The difference should not be important, as the range of vitrification of the two clays is essentially the same. The clay burns salmon-colored and becomes buff at higher temperatures.

A small brickyard was started many years ago in secs. 14 and 15, T. 35 N., R. 22 W., just west of North Branch, on some patches of red drift that come to the surface through the prevalent gray drift.

At Taylors Falls red laminated clay is exposed on the Wisconsin side but is covered with gray drift in Minnesota. Similar red laminated clay, exposed near Sunrise, was used in 1856. These clays crop out along St. Croix River in Chisago County and near by and are of the type so extensively used at Menomonie, Wis.

Siliceous shale of Cambrian age crops out in a layer not more than 10 feet thick in the bluffs below The Dalles at Taylors Falls, about 30 feet below the railway track. Though of fair quality it is probably too thin and inaccessible to use. It softens in water but does not slake. After grinding, it can be molded with 20 per cent of water and develops a strength of over 50 pounds to the square inch. Its air shrinkage is 3.5 per cent. As burned at the Minnesota School of Mines experiment station, it gave the following results:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
05	Salmon	0	17
03	....do.	0	16
01	....do.	1	15
1	Red	5	7
3	....do	6	2

The clay becomes too hard to scratch with a knife at cone 03 (1,994° F.) and becomes viscous at cone 3 (2,174° F.), a range of 180° F. If abundant it could be used for hard-burned products.

CLAY COUNTY.

Clay-bearing formations:
- Pleistocene:
  - Silts of the Red River valley.
  - Gray drift.
- Cretaceous: Shale.

Dark-blue Cretaceous shales were found at Fargo, N. Dak., across the river from Clay County, at a depth of 220 feet and are known to be more than 40 feet thick. They no doubt extend into Clay County.

At Moorhead several plants have been built to use the thin upper leached and oxidized portion of the silts of the Red River valley. Only 16 inches of the clay is of good quality, and an admixture of the underlying clay causes too much trouble in drying. To work so thin a clay a large area is necessary, and most plants strip the few inches of soil from the workable clay and spread it over the shallow pit from which the clay has already been removed. This allows the continuous use of the soil for farming, except over the few acres that are being actively worked. The clay slakes in one minute, and its plasticity is low, as it requires 22 per cent of water for molding. Its tensile strength is well above 100 pounds to the square inch, even when rapidly dried, and its air shrinkage is 5 per cent. As burned at the University of Minnesota it gave the following results:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
04	Buff	0	33
01	....do	0	33
2	....do.	1	29
4	....do	3	25
5	....do	7	15

The clay becomes hard at cone 3, although satisfactory brick can be made at somewhat lower temperatures. Its fusion temperature was rather higher than that of most of the clays that contain so much lime, and its range of vitrification was nearly 200°. The plants that have been operated in this neighborhood made soft-mud bricks on a rather small scale. They are no longer operated.

At Barnesville samples were taken at two points, one a mile east of the town and one about the same distance north, at an old brick-yard. Each sample included several feet of the blue clay as well as the very thin layer of leached material on top. One of them contained a little gypsum in scattered crystals. The clays slake in two minutes and are highly plastic, requiring 29 per cent of water for molding. When very carefully dried their strength is more than 100 pounds to the square inch, but they crack to pieces unless care is used. 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. A burning test resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
04	Buff	1	27
02	----do	2	20
1	----do	7	13
2	----do	13	4

The clay is too hard to be scratched with a knife after burning to cone 02 (2,030° F.) and reaches viscosity about cone 3 (2,174° F.). The clay from sec. 29, T. 137 N., R. 45 W., about a mile east of Barnesville, behaves slightly better in the fire than that north of the town.

CLEARWATER COUNTY.

Pleistocene gray drift is the only clay reported in Clearwater County, and it needs the usual cleaning before it can be used successfully. Lakes are notably less abundant than in neighboring counties.

COOK COUNTY.

Red clays are reported to occur in considerable abundance in Cook County and are apparently like the so-called "water-laid moraine" so common around the west end of Lake Superior. A sample sent to the University of Minnesota in 1897 by Chester McKusick was analyzed by C. P. Berkey, with the following result:

Analysis of red clay from Cook County.

Silica	53.390
Alumina	14.259
Iron oxide	13.706

Lime	3.033
Magnesia	1.740
Alkalies	Not reported.
Combined water	9.995
Carbon dioxide	4.278
	100.401

COTTONWOOD COUNTY.

Clay-bearing formations { Recent: Lake clay. Pleistocene: Gray drift. Cretaceous: Shale. }

About half a mile from Windom station a deposit of gray drift has been explored to a depth of 8 feet over a great many acres, and in parts of the neighborhood is undoubtedly thicker. It is covered with sandy drift to a depth of 1 to 8 feet but is near the surface over many acres. The clay slakes in two minutes and is fairly plastic, requiring 24 per cent of water for molding. Its tensile strength is about 150 pounds to the square inch and its air shrinkage is 6 per cent. As burned by the Minnesota School of Mines experiment station it gave the following results:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
03	Salmon	1	20
01	do	4	17
1	Brown	7	5
3	do	8	1
5	do		

The clay burns hard at cone 03 (1,994° F.) and is viscous at about cone 3 (2,174° F.). An attempt was made to use this clay in the Windom Brick & Tile Factory, and it is said that the buff or yellow brick produced have stood satisfactorily in buildings in the neighborhood.

A lake clay from the northeast side of Bingham Lake, which has been used by the Bingham Lake Brick & Tile Co. since 1904, extends for only a few acres to a depth of about 9 feet. A few small limestone pebbles have been washed into the upper layers of the clay, but the main part of the deposit is entirely free from them. The clay slakes in one minute and is highly plastic, requiring 32 per cent of water for molding. The tensile strength is more than 125 pounds to the square inch, but this is decreased somewhat by rapid drying. The air shrinkage is 7 per cent. As burned by the Minnesota School of Mines experiment station this clay gave the following results:

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

The clay becomes too hard to be scratched with a knife at about cone 03 (1,994° F.) and reaches viscosity at cone 2 (2,138° F.). The company specializes in the manufacture of tile rather than brick, producing about 650,000 tile a year.

Cretaceous shale has been reported in the records of some wells drilled in this county. It lies below about 300 feet of drift and sand.

CROW WING COUNTY.

Clay-bearing formations { Pleistocene: Gray laminated clay. Red drift.

About a mile northeast of Brainerd a yard was started in 1876 to produce cream-colored brick from laminated clays exposed in the Mississippi River bluff near the dam. The clay is overlain by about 20 feet of sand, and where protected by the sand from weathering is uniformly gray in color and conspicuously laminated. The work has been abandoned, as most of the easily accessible clay has been used up, and the removal of 20 feet of sand to obtain 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 exposures are not numerous and none are reported closer to the town. The clay slakes at once and shows fairly high plasticity, requiring 24 per cent of water for molding. Its air shrinkage is 4 per cent and its tensile stength well above 100 pounds to the square inch, even when rapidly dried. Burning tests by the Minnesota School of Mines experiment station gave the following results:

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

The clay becomes too hard to be scratched with a knife at cone 01 (2,066° F.) and reaches viscosity at cone 4 (2,210° F.).

In 1886, at about the time the clay along the river was abandoned, an outcrop of similar laminated material was found a few hundred yards to the east, where a tributary stream had eroded the overlying sand. A brickyard is now in operation on this deposit, and the material found is essentially similar in character to that described above, although its upper part has been leached and oxidized yellow. It seems somewhat more sandy and burns to a red brick. The bottom clay, not used at present, will burn buff. The clay is probably available without too much overburden under about 200 acres of land. It slakes in 4 minutes, is highly plastic, and requires 24 per cent of water for molding. Its tensile strength is only about 50 pounds to the square inch, and its air shrinkage is 8 per cent. Burning tests resulted as follows:

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

The clay becomes hard after burning at cone 05 (1,922° F.) or less and viscous at cone 1 (2,100° F.). This is a better range of vitrification than that of the average gray laminated clay. The plant has a capacity of 20,000 brick a day, but works only half-day shifts. It produces sand-mold common brick. Wood is used for fuel. The clay would probably yield hollow brick and fireproofing if properly treated.

An effort was made to find clay suitable for common brick near the new towns springing up on the Cuyuna iron range. Two types of clay are available—the red drift and its worked-over material in numerous swamps and along lake shores. A sample of red drift from the boat landing near the edge of the town of Deerwood gives good red brick. The clay slakes readily, is very plastic, and has a tensile strength of about 100 pounds to the square inch. It becomes hard at a low temperature, with moderate to high shrinkage, but does not become viscous if burned slowly and well oxidized. Its range of vitrification is from cone 010 (1,742° F.) to cone 01 (2,066° F.). If an attempt is made to utilize large bodies of the clay it will probably be found necessary to use rolls to remove pebbles, but these pebbles are not limestone and in the sample taken they did not prove injurious.

The nature of the swamp clays along the Cuyuna range is probably well shown by a test made on clay from the south side of the lake at Deerwood station. The spur track to the Adams mine passes through a cut mostly in a clay bank about 100 paces long. The deposit is roughly stratified and sandy, but the more argillaceous parts probably represent the types of clay formed by wash from the red drift of the neighborhood. The clay slakes at once, and the sandy portions have a tensile strength of only about 60 pounds to the square inch. The brick are salmon-colored at low temperatures and become red and hard below cone 02 (2,030° F.). They reach viscosity only when heated above cone 3 (2,174° F.). The shrinkage in drying and burning is small, but the brick are rather porous. They should be wholly satisfactory if burned to cone 02 (2,030° F.).

Samples of several similar clays have been sent in from a swamp deposit overlying manganese iron ore at the Northland mine in sec. 20, T. 47 N., R. 28 W. This deposit must be moved in preparing for mining operations. One sample contained a few limestone pebbles, but two others made excellent brick. They were hard at 1,850° F. and reached viscosity at 2,050° F. Some of these available swamp clays should be used.

DAKOTA COUNTY.

Clay-bearing formations:
- Recent: Alluvium.
- Pleistocene:
  - Loess.
  - Red and gray drift.
- Ordovician: Decorah shale.

The Pleistocene and Recent clays are not important in Dakota County. A small brickyard at West St. Paul, about half a mile from the large plant of the Twin City Brick Co., uses leached sandy drift which possibly originated as glacial outwash. It is of variable thickness but covers many acres. It slakes at once and has rather low plasticity, though it requires 28 per cent of water for molding. Its tensile strength is over 100 pounds to the square inch, and its air shrinkage is less than 4 per cent. Burning tests resulted as follows:

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

The clay becomes hard at cone 01 (2,066° F.) and just reaches viscosity at cone 5 (2,246° F.). It should therefore be readily burned to a very excellent hard product. The plant that has been working this deposit was relatively small and has been practically abandoned because of unfavorable shipping conditions and proximity to large brick plants.

The principal clay-bearing formation in Dakota County is the Decorah shale, which is best developed along the Mississippi River bluffs at West St. Paul. Only a small patch is exposed in West St.

Paul (see Pl. X), but this patch is remarkably well situated economically and has the maximum thickness attained by the formation. In West St. Paul and Mendota the generalized geologic section is as follows:

Section of Decorah shale at West St. Paul.

	Feet.
Drift	65
Decorah shale:	
Shale and limestone (many layers of limestone)	40
Limestone, hard	3
Shale (½-inch lenses of limestone)	40
Limestone	1½
Shale	3
Platteville limestone	12

The lower part of the large body of shale seems to differ slightly in character from the higher shale beds which alternate with the limestone. (See fig. 18.)

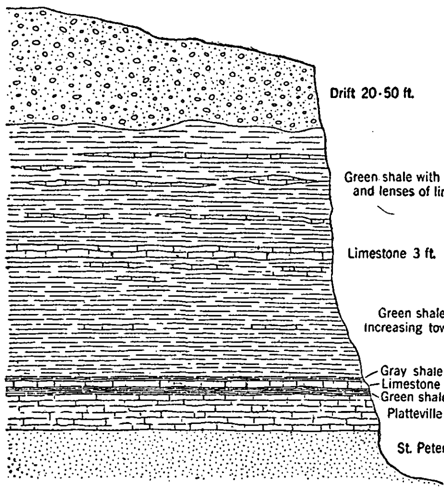


FIGURE 18.—Geologic section at shale quarry, West St. Paul.

The lower shale is smooth and green in color, slakes in two minutes to scales and small lumps, and is very highly plastic. It requires 28 per cent of water for molding, has a tensile strength of nearly 200 pounds to the square inch, and is unaffected by rapid drying. Its tensile strength is remarkable in that two pieces which have been cut apart, as by the auger machine, readily adhere with about as much strength as before, without application of very great pressure. 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 it tends to form black cores, with the consequent swelling and destruction of the brick, but if carefully oxidized in the early part of the process the results are as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
010	Salmon	4	12
06	do	6	9
04	Red		
05	Brown		

The clay burns too hard to be scratched with a knife at cone 010 (1,742° F.) and is not yet viscous at cone 02 (2,039° 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."

The upper shale is picked over by hand at the plant, to separate most of the limestone layers and lenses, before it is sent to the crushing machine. It gives a product of essentially the same sort as that from the lower shale, except that the colors are lighter, probably owing to the presence of some lime that is not completely separated, and possibly also to a difference in the amount of iron present. The clay slakes irregularly, owing to variations in the amount of calcareous cement, and needs to be ground before tempering. With 23 per cent of water it is very highly plastic. Its shrinkage and strength are similar to that of the lower shale. A burning test resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
010	Salmon	0	19
05	Red	1	21
1	Brown	1	13
3	Green	2	11

At all temperatures tested (1,688° to 2,200° F.) the clay burns to hard fine brick. With rapid heat black cores develop. The porosity is never low, but with careful oxidation the brick can be heated above cone 3 and thoroughly vitrified without danger of loss. By changing the atmosphere in the kiln toward the end of the burn a variety of colors can be produced. The range of vitrification for both clays is very great and is surprising in a clay of such low fusion temperature.

The following analyses of Decorah shale have been made by F. F. Grout:

Analyses of shale from West St. Paul.

Chemical analyses.				Mechanical analysis of lower shale.	
	1	2	3		
Silica	56.35	54.66	50.81	Fine clay	37.8
Alumina	18.63	24.04	20.25	Coarse clay	13.2
Iron oxides	6.19	6.53	5.18	Silt	46.8
Titanium oxide	.65	.66	.50	Fine sand	1.5
Lime	.96	.45	4.05	Coarse sand	.7
Magnesia	2.97	1.08	2.13		
Soda	.25	.47	.28		100.0
Potash	7.37	5.37	5.69		
Moisture	2.41	2.35	2.16		
Ignition	4.81	5.15	8.92		
	100.59	100.76	99.97		

1. Lower shale, sampled at the base of the brick company's quarry.
2. Lower shale, sampled by another company.
3. Upper shale, sampled by another company.

The plant of the Twin City Brick Co., one of the largest in the State, is at the boundary between West St. Paul and Mendota. The quarry is very extensive, and the kilns have a capacity of nearly 100,000 brick a day. The company produces brick and hollow ware. Brick are burned to about 2,100° F., the temperature varying considerably according to the type of product desired. The types produced vary according to the proportion of upper and lower shale used, to the temperature used in burning, and to the supply of fuel and air at the different stages of burning, resulting in oxidation and reduction. Work was begun in this neighborhood more than 20 years ago and has progressed with many changes in method and organization, and the final consolidation and success have been due largely to the present careful management. Market conditions are of course excellent. Details of manipulation have been patented; and ingenious devices, especially methods of quarrying and a chain conveyor, have been developed that are worthy of careful study by anyone planning to use the Decorah shale. Although the shale burns red under normal and laboratory conditions the color can be altered by controlling the fuel supply and by shutting off the air supply. Fancy brick, front brick, and klinker brick are produced in so great quantities and bring prices so high that the production of common brick has practically ceased at this plant. One of the many interesting special products is an interlocking tile for building block.

Prof. Talbot, of the University of Illinois, who has tested the products made in West St. Paul, reports a crushing strength of 1,100 pounds to the square inch for hollow block about 4 by 4 by 13 inches with horizontal opening and a strength of 3,500 pounds to the square inch for hollow block about 4 by 4 by 4 inches with vertical opening. The city building inspector of Minneapolis found a crushing strength of 900 pounds to the square inch as an average of 10 tests on hollow blocks 4½ by 4½ by 12½ inches, and of 3,300 pounds to the square inch (minimum 1,775 and maximum 6,250) as an average of 10 tests on solid bricks.

DODGE COUNTY.

Clay-bearing formations:
- Pleistocene:
  - Gray laminated clay.
  - Gray drift.
- Ordovician: Decorah shale.

Gray drift, such as is being worked at West Concord for the manufacture of draintile, covers most of Dodge County but contains numerous pebbles. In the eastern part of the county, along the headwaters of the branches of Zumbro River, the Decorah shale and the Galena limestone crop out. The Decorah shale probably underlies most of the county and is the most promising formation for the manufacture of clay products. It can best be developed in the vicinity of Mantorville and Kasson, where it is available within a mile or two of the railroad and has only a moderate overburden.

In the brickyard at West Concord a pit has been opened in 8 feet of gray drift, which extends over many acres. Some of the land is swampy. The pebbles are not so numerous as in the average gray drift but they nevertheless caused the failure of an attempt to use the clay. The geologic relations, as well as the scarcity of the pebbles, indicate that the gray drift belongs to the older (Kansan) ice invasion. After fine grinding, the clay shows low plasticity and requires 22 per cent of water for molding. Its air shrinkage is 6 per cent. As burned by the Minnesota School of Mines experiment station, it gave the following results:

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

The clay becomes too hard to be scratched with a knife at cone 02 (2,030° F.) and is still undeformed at cone 6 (2,282° F.). The plant has a capacity of about 8,000 tile a day. Fine grinding and burning to a fairly high temperature would probably make it possible to use this clay with satisfactory results. Similar deposits in other abandoned. Samples of better clays have been sent in from the West Concord Clay Products Co., indicating new discoveries.

Gray laminated clays occur about 2 miles southwest of Hayfield, on the Chicago Great Western Railroad, in a deposit that covers many acres to a depth of 30 feet. This deposit has been exposed along the banks of the creek and is mostly blue and sandy, though weathered yellow near the top. The clay has almost no overburden along the creek but is covered by 15 feet of soil and drift a short distance away. A few small pebbles were observed, but they do not seem to be a serious defect. The clay slakes in four 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 about 150 pounds to the square inch, even when rapidly dried. Burning tests resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
05	Salmon	1	16
02	....do	2	13
01	....do	2	13
2	Brown	6	5
4	....do	....	....

The clay becomes hard after burning to cone 02 (2,030° F.) and reaches viscosity at cone 4 (2,210° F.). If market conditions are favorable this material should be used.

DOUGLAS COUNTY.

Clay-bearing formations { Recent: Lake clays. Pleistocene: Gray drift. }

Attempts have been made at many points in Douglas County to work the gray drift for common brick, and where the limestone pebbles are less abundant than usual these attempts have met with some success. At Alexandria gray drift is found close to the railroads. A sample taken at the intersection of the Great Northern and Minneapolis, St. Paul & Sault Ste. Marie lines was very much like the material used at Hutchinson, having almost the same proportion of sand and clay and about 7 instead of 9 per cent of lime. Similar drift is exposed on Abbotts Point, on the north side of Lake Miltona; at Effington; and elsewhere. This drift has been tested and would require cleaning to remove the pebbles.

Near Alexandria two small brickyards are 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 apparently extends over 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 in practice it is greatly reduced by adding 35 to 40 per cent sand. Most of the available sand, however, contains a good deal of lime, and too great additions are decidedly injurious. A burning test resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
04	Salmon	0	18
01	Red	6	6
2	Brown	8	1

If care is used in oxidation this clay can be burned to good hard brick. The addition of sand might assist in the oxidation. Viscosity is reached at cone 3 (2,174° F.).

At the northeast edge of Alexandria the McKay Brick Co. for several years made brick from a bog deposit extending over 10 acres and more than 5 feet deep, though so wet that only 5 feet of it was used. Very few pebbles have been washed into this deposit. The clay is so rich that 10 to 15 per cent of sand is usually added. The sand is obtained conveniently at several points in the neighborhood. On the high ground it overlies the clay. The clay slakes in two minutes and is highly plastic, requiring 22 per cent of water for molding. The tensile strength is 175 pounds to the square inch and is well above 100 pounds even if carelessly dried. The air shrinkage is 4 per cent. As burned at the Minnesota School of Mines experiment station the clay gave the following results:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
05	Salmon	2	15
02	....do	3	12
1	Red	5	8
3	....do	6	6
5	....do	7	3
6	Brown	7	2

The clay burns too hard to be scratched with a knife at cone 03 (1,994° F.) and reaches viscosity at cone 6 (2,282° F.). It should yield an excellent hard vitrified product, though apparently it has been used only for a good grade of common brick. The deposit is situated conveniently to the railroad, but 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 clays may be partly of glacial origin and partly more recent. The outlet of the lake is being eroded and the lake level is being lowered, exposing even the recent deposits. The clay, which is overlain by 3 or 4 feet of sandy soil, contains some ferruginous concretions. It slakes in three minutes and is very highly plastic, requiring 31 per cent of water for molding. Its tensile strength is 180 pounds to the square inch but is considerably reduced by rapid drying. Its shrinkage on drying is 7 per cent. Burning tests resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
04	Buff	1	27
02	....do	2	25
2	....do	13	12
3	....do	14	1
4	Greenish buff	14	1

The clay is hard after burning to cone 02 (2,030° F.) and reaches viscosity at cone 4 (2,210° F.). It should be exploited if there is a demand for buff brick in the neighborhood.

FARIBAULT COUNTY.

Clay-bearing formations:
- Pleistocene:
  - Gray laminated clay.
  - Gray drift.

Gray drift covers almost all of Faribault County but is too pebbly at most places to be of much economic importance. Laminated clay has been used at Blue Earth for brick and tile. The only clay plant in operation in the county is one at Winnebago that uses drift. Blue Earth ships gray laminated clay for use at the Fairmont plant in Martin County.

The Blue Earth deposit is known to be 20 feet deep over 10 acres and probably has much greater dimensions both vertically and areally. It is covered by only 2 or 3 feet of soil and near the top includes a layer that contains many lime pebbles. The clay slakes in two minutes and is highly plastic, requiring 33 per cent of water for molding. Its tensile strength is 200 pounds to the square inch, but if rapidly dried the brick check badly. Its air shrinkage is 8 per cent. Burning tests resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
05	Red	3	21
03	....do	6	12
01	....do	7	10
2	....do	10	1

The clay burns hard at cone 04 (1,958° F.) and reaches viscosity at cone 2 (2,138° F.). It must be well oxidized in burning to avoid the formation of black cores.

This clay was used at Fairmont, in Martin County, by the Fairmont Drain Tile & Brick Co., in a plant whose capacity is 25,000 tile a day. The plant was erected at a cost of $150,000 to use a local clay, but this was found to be so full of limestone pebbles as to be quite useless. The whole surrounding country was prospected for a suitable clay, but only two or three available deposits were found. The Blue Earth material is the only Minnesota clay now used, but small amounts are imported from Mason City, Iowa. Hollow brick and tile were produced.

Along the Chicago, Milwaukee & St. Paul Railway tracks west of Winnebago a 30-foot deposit of clay covered by only 2 or 3 feet of soil extends over about 70 acres. It contains some limestone pebbles, especially near the top, and care has to be used also to avoid auger lamination. However, the Winnebago Hollow Block & Tile Co., which uses the clay, is said to counteract the effects of the lime very satisfactorily by treating the clay with salt. The salt seems to react with the lime pebbles, forming around the burned pebble a vitrified shell that prevents it from slaking and breaking the product when exposed to the weather. The salt also improves the behavior in drying. One short scoopful of crude salt is added to 1½ yards of clay that has been disintegrated in a hammer crusher. This is followed by thorough tempering in pug mill, feeder, and auger machine. Too much salt makes the product " off color "—a lighter salmon tint than good tile usually are—and too little salt does not correct the natural defects due to the limestone. The capacity of the plant is about six carloads of tile a day.

At Wells, about half a mile north of the station, leaching has made the limestone pebbles less numerous than in the average gray drift. The clay was sampled in a 10-foot boring. It slakes in two minutes and with 27 per cent of water shows medium plasticity. Its shrinkage on drying is 6 per cent. Burning tests resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
06	Salmon	1	24
03	....do	1	22
1	Red	7	10
3	....do	8	3

The clay is hard after burning at cone 03 (1,994° F.) and reaches viscosity about cone 4 (2,210° F.). This behavior seems to be desirable, but the presence of a few limestone pebbles would be a serious defect, and the amount of clay available without a superabundance of pebbles should be determined before a plant is built.

FILLMORE COUNTY.

Clay-bearing formations:
- Pleistocene: Loess.
- Cretaceous: Clay.
- Devonian: Shales (unimportant).
- Ordovician:
  - Maquoketa shale: Shales (unimportant).
  - Galena limestone: Shales (unimportant).
  - Decorah shale: Shale.
- Cambrian: St. Lawrence formation: Shales (unimportant).

The loess deposits are the only clays notably exploited in Fillmore County, but attention should be paid to the widespread Decorah shale,

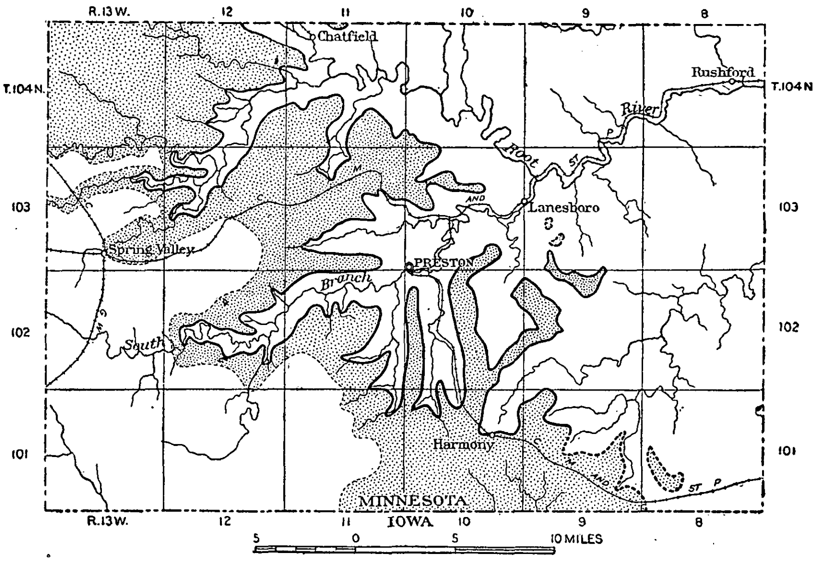


FIGURE 19.—Map of Fillmore County. Dotted area is underlain by Decorah shale.

and careful prospecting is recommended for the clays thought to be Cretaceous.

The Decorah shale lies at altitudes of 1,070 to 1,130 feet and has an average thickness in Fillmore County of only about 20 feet. It is exposed principally in terraces and benches along the banks of Root River and its branches, and it constitutes a persistent spring horizon. (See map, fig. 19.) Preston, the county seat, has an abundance of these green shales, some of which are favorably situated for development. Chatfield is also well supplied. A sample from Elmira Township proved to work and burn essentially like the shales at West St. Paul, though there were some indications that rapid drying might be harmful. The range of vitrification is more than 400° F. (cone 010 to cone 2). The fire shrinkage is about 4 per cent, and the burned brick have a low porosity. This shale is not used in the county but is recommended as the most valuable material available.

Although clays thought to be of Cretaceous age occur in Fillmore County, they have not been developed. Half a mile north 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 nearly 20 feet thick, and is estimated to extend over 30 acres. It is red near the surface but gray and carbonaceous below. It is slightly gritty and has a few ferruginous concretions. 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 red and becomes hard at a low temperature, not over 1,650° F. If rapidly heated, the organic matter causes swelling and black cores, but if fully oxidized it can be heated above cone 2 (2,138° F.) without deformation, a range of 500° F. It should therefore yield good vitrified ware. The absorption is easily reduced to less than 4 per cent, but the fire shrinkage is high.

In the eastern two-thirds of Fillmore County the loess forms a mantle 2 to 20 feet thick over the Paleozoic formations. Its greatest thickness is seen at the bases of the slopes along the valley. On the high prairie land it is not so thick but is much more evenly distributed. Many yards now abandoned have used it in the past, as at Rushford, Peterson, Whalen, Lanesboro, Fountain, Spring Valley, Carimona, Forestville, Harmony, and Mabel. Material for red brick is available at all these places to-day. (See fig. 9, p. 99.)

One of the thickest loess deposits is at Preston, where the following section is exposed (see fig. 20):

Section of loess at Preston.

	Ft.	in.
Loess loam		6
Yellow loess	10	0
Bluish-gray loess (depth unknown)	5+	

The yellow loess is used; the blue-gray material is reported as more plastic and not so well adapted for use in a sand-mold brick plant. The deposit is very extensive and will furnish material for good common brick for many years. The plant, which is about a mile north of Preston, has a capacity of 30,000 brick a day and is usually active. The yellow clay slakes in one minute and shows a rather low plasticity, requiring 23 per cent of water for molding. Its air shrinkage is about 3 per cent and its tensile strength about 150 pounds to the square inch. Burning tests resulted as follows:

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

The clay becomes hard at cone 04 (1,958° F.) and reaches viscosity at cone 4 (2,210° F.).

A sample of the underlying blue clay showed essentially the same properties, and there was no reason to think from the tests made

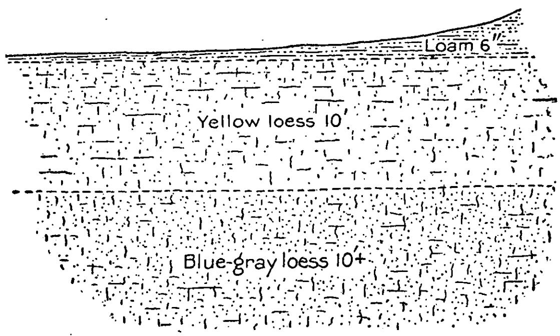


FIGURE 20.—Section of the loess at Preston.

that it would not work equally well in the brick machine or in burning. It was a little more porous as burned to the low temperature and required a slightly higher temperature to make it steel hard. The following analyses, by F. F. Grout, show the siliceous nature of the loess exposed at the brickyard:

Analyses of loess from Preston.

Chemical analysis.

Silica	71.53
Alumina	8.07
Iron oxide	5.63
Magnesia	1.74
Lime	2.36
Soda	1.85
Potash	1.97
Ignition	4.50
Water	2.30
Titanium oxide	.31
	100.26

Mechanical analysis.

Fine clay	6.2
Coarse clay	8.5
Silt	84.3
Fine sand	.9
Coarse sand	.1
	100.0

The other formations in Fillmore County show very little promise of containing available shale. The area mapped as Maquoketa shale by the Winchell survey is surrounded by Devonian beds, to which the so-called Maquoketa is so similar in physical character that it is questionable whether this also is not Devonian. It was sampled at the Etna mill. The Devonian material was sampled at the place where Bear Creek crosses the line between Mower and Fillmore counties. The samples are very much alike and do not differ widely from samples of shales from the St. Lawrence and Galena formations in this county. All the beds are thin, with alternating sandy and dolomitic layers.

The Devonian shale slakes to shaly lumps in a few minutes and is highly plastic with 20 per cent of water. The tensile strength is about 100 pounds per square inch, and the shrinkage on drying is 3 per cent. Burning tests resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
06	Buff	0	26
02	....do	0	26
1	....do	0	26
3	....do	0	30
5	....do	3	20
6	....do	....	....

The clays are burned hard at cone 1 (2,102° F.) and reach viscosity at cone 6 (2,282° F.).

The shale from the Galena limestone, sampled on the State road in the SE. ¼ sec. 1, T. 104 N., R. 11 W., southeast of Chatfield, is

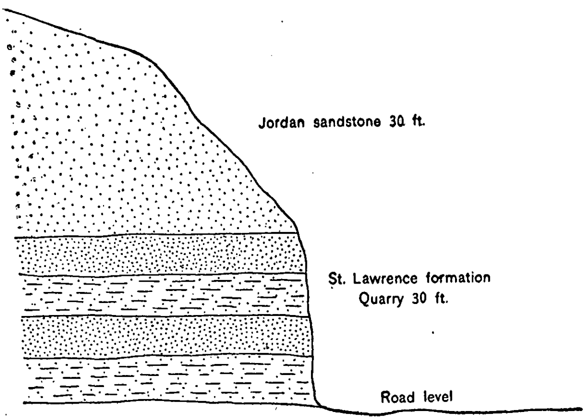


FIGURE 21.—Section at quarry west of Rushford.

green, and lies in layers not more than 20 inches thick. Its physical behavior is almost like that of the Devonian shale, except that it requires a higher temperature (cone 4) to produce a hard brick.

The shale of the St. Lawrence formation is exposed in the city quarry, half a mile west of Rushford, where it alternates with the quarry rock. (See fig. 21.) The quarry refuse, including the shale, is used as road material. The sample taken proved to be very sandy and showed no shrinkage on drying. A burning test resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
05	Salmon	0	29
01	.....do	0	29
1	Brown	1	28
4	.....do	2	24
6	.....do	....	....

The clay becomes hard after burning to cone 0.2 (2,030° F.) and reaches viscosity about cone 5 (2,246° F.).

FREEBORN COUNTY.

Clay-bearing formations:
- Recent: Swamp clay.
- Pleistocene:
  - Gray laminated clay.
  - Gray drift.

The glacial drift in Freeborn County is too pebbly to be of much value. The only two clay plants being worked are at Albert Lea and Glenville, but ruins of an abandoned plant remain at Conger. Blue-gray or yellow laminated clays are used, and new deposits of this nature may be discovered at several places in this region.

Within a mile north of Glenville the Acorn Brick & Tile Co. has developed a deposit of laminated clay more than 10 feet thick, which extends over at least 10 acres. Where exposed the color is oxidized to a yellowish brown. The overburden is 2 to 3 feet thick. A few limestone pebbles or concretions occur but are not so abundant as to be a serious drawback. 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 very low. The briquets show flaws that have developed in drying, and careful work would probably be required to avoid auger structure. A burning test resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
05	Salmon	0	25
04	.....do	1	24
02	Red	6	12
2	.....do	10	2
3	.....do	....	....

The brick are hard after burning to cone 04 (1,958° F.) and reach viscosity at cone 3 (2,174° F.) The plant that worked this clay produces a few brick and a large number of draintile, but it was not operating at the time of the writer's visit.

About 2½ miles southeast of Conger is a 30-foot deposit of laminated clay that extends over nearly 100 acres. The section includes 3 feet of black soil, underlain by 8 or 10 feet of yellowish clay, below which is the blue or gray clay, and at the base a gravelly streak. In 1904 a company was organized to work this deposit, but shipping facilities were unsatisfactory, and the work ceased after about four 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 distant point. No tests were made to determine whether the blue and gray clays were similar.

At Albert Lea the Albert Lea Brick & Tile Co. has a plant just north of the city limits, at a hill of perhaps 25 acres. The section comprises an overburden of 2 or 3 feet of soil, 16 feet of yellow clay, and 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 low tensile strength, about 60 pounds to the square inch, which is greatly lowered 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 to the square inch, even when rapidly dried. The adhesion of two wet pieces of clay after being pressed together and dried was not very great, indicating that auger lamination may be serious. This also has been the experience of the company, which has sought to overcome the trouble by adding to the clay about 25 per cent of nonplastic material such as cinders, burnt clay, or sand. The drying shrinkage of the blue clay is 6 per cent and of the yellow 3 per cent, though the experience of the company has been that the blue clay dried more safely than the yellow. As burned at the Minnesota School of Mines experiment station, the clays gave the following results:

Blue clay.

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

Yellow clay.

Cone No.	Color.	Shrinkage.	Absorption.
05	Salmon	1	37
03	Buff	1	36
1	do	1	36
2	Greenish yellow		

The clay burns to a fairly satisfactory product at these lower temperatures but does not become very hard until near the temperature of viscosity. The range of vitrification is approximately from cone 1 to cone 2. A mixture of the blue and yellow clays stood the burning tests very much as the clays did separately. The plant has for some time produced 10,000 tile a day, using circular downdraft kilns.

Although preheating effects a remarkable improvement in molding and drying this clay, it can not make vitrification possible. Bleininger[1] says:

An extremely fine grained clay from Albert Lea, Minn., 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 0.577 millimeter in diameter	.21
Average 0.0354 millimeter in diameter	1.04
Average 0.0167 millimeter in diameter	.96
Average 0.005 millimeter in 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 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 is remarkable in this clay at 350°. 95 per cent of the brick were cracked before; 0 per cent after. A proposed test for plasticity using the absorption of a colored dye indicates a much greater plasticity than in the other clays tested in this same study.

The following analysis of this clay was made by G. W. Walker, of the University of Minnesota, for Mr. Rusfeldt, of the Albert Lea Brick & Tile Co.:

Analysis of laminated clay from Albert Lea.

Silica	54.90
Alumina	13.94
Iron oxide	5.15
Lime	7.36
Magnesia	3.28
Potash	1.88
Soda	2.13
Titanium oxide	.84
Loss on ignition	12.54

A deposit of extremely fine grained silty clay, possibly of the nature of fuller's earth, occurs in a swamp on the east side of Rice Lake, in secs. 11, 12, 13, and 14, T. 103 N., R. 20 W. The material

[1] Bleininger, A. V., Effect of preliminary heat treatment upon drying of clays: Bur. Standards Bull. 7, No. 2, 1911.

could probably be used for common brick or draintile. The following analyses are available, the first two made by A. D. Meeds and the next two by G. B. Frankforter, both of Minneapolis:

Partial analyses of swampy clay from Albert Lea.

	1	2	3	4
Silica	55.52	57.60	59.37	57.62
Alumina	13.55	14.19	11.82	14.36
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

NOTE.—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.

Clay-bearing formations:
- Recent: Alluvium.
- Pleistocene:
  - Loess.
  - Gray drift.
- Cretaceous: Clay, sewer pipe, and stoneware.
- Ordovician: Decorah shale.

Goodhue County is remarkable for having more workable high-grade clays than any other county in Minnesota. The most valuable are those of Cretaceous age.

DECORAH SHALE.

The Decorah shale in this county (see Pl. X and fig. 22) is almost identical in section and in detailed behavior of the clay with that at West St. Paul, Dakota County, where it is extensively used. The shale is being used at Zumbrota and Wanamingo (see fig. 23), and a company is being organized to develop it at Cannon Falls, where it has been explored over hundreds of acres. At the plant of the Zumbrota Clay Manufacturing Co., in Minneola Township, the shale is equally extensive. (See fig. 24.)

Clay from the Wanamingo plant slakes somewhat irregularly but becomes highly plastic with about 30 per cent of water. The air shrinkage is 8 per cent. Burning tests resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
06	Red	3	15
04	do	3	14
02	do	7	3
2	do	8	1
5	do		

If the clay is too rapidly heated black cores and blebby structure develop, but with careful oxidation the bricks become too hard to scratch with a knife after burning to cone 06 (1,886° F.) and reach viscosity at cone 3 (2,174° F.). It is clear that the slow, steady decrease in porosity indicated by the absorption is favorable for the production of vitrified ware. The plant has a capacity of 120,000 brick a day but is now producing hollow ware of several sorts in preference to brick. It was planned to use electric power from Cannon Falls. The property has changed hands several times and now appears to be operating at a profit.

In Minneola Township the Zumbrota Clay Manufacturing Co.'s plant used a rather massive bed of the shale 15 feet thick. Tests by the Bureau of Standards gave uniform vitrification, with increase

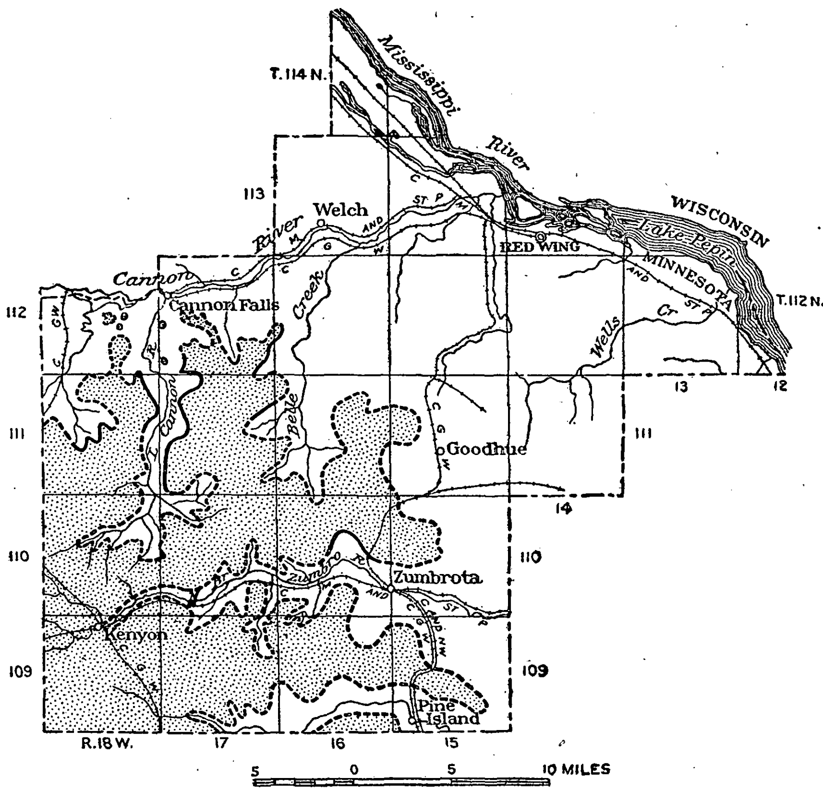


FIGURE 22.—Map of Goodhue County. Dotted area is underlain by Decorah shale.

of temperature, to a very low porosity. The best temperature of burning (as is characteristic of the Decorah shale) is rather lower than for most other good clays. In all physical tests this clay resembles the average Decorah shale. The plant has a capacity of about 50,000 brick a day but makes draintile and hollow brick in addition to common brick. Six hollow building blocks with two holes lengthwise tested on the side and on the edge by the Minneapolis building inspector gave an average strength of 330 pounds to the square inch, and one block tested on the end showed 5,100 pounds to the square inch.

Around Cannon Falls the overburden of the Decorah shale is nowhere more unfavorable than at West St. Paul, where the shale is now used. Samples were taken on the land of F. E. Tate, 3 miles south of Cannon Falls, and on property of the Goodhue County Clay

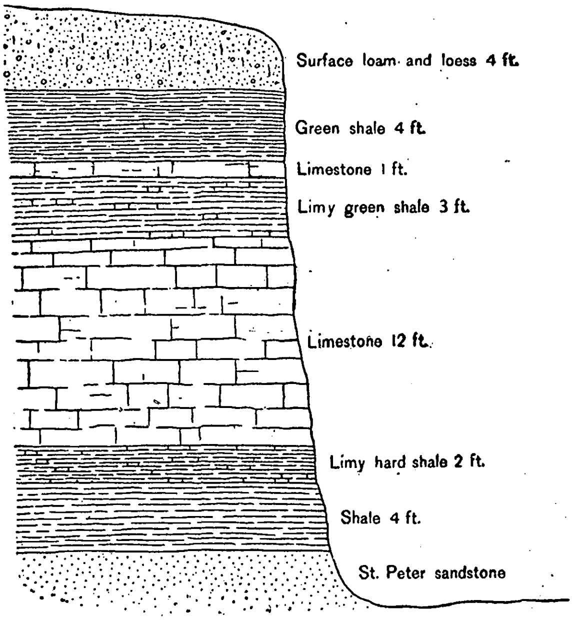


FIGURE 23.—Geologic section at Wanamingo.

Co., 1½ miles southeast of Cannon Falls. These exposures and others in the region are essentially alike. The shale slakes only to lumps but is very highly plastic with 30 per cent of water. The tensile strength is 130 pounds to the square inch and is not greatly reduced by rapid drying. The clay works well in an auger machine. The shrinkage on drying is 8 per cent. Burning tests resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
010	Salmon	4	15
06	Red	6	8
03	do	7	6
01	do		3
2	Brown		

The clay must be well oxidized to prevent the formation of black cores, but this can be done with no great difficulty. The brick are hard after burning to cone 010 (1,742° F.) and reach viscosity very gradually at about cone 1 (2,102° F.). The shale seems to be similar to that at St. Paul. A company has been organized and is building a plant at Cannon Falls to use the shale.

CRETACEOUS CLAYS.

The stoneware and sewer-pipe factories at Red Wing, which are famous for their high-grade products, derive their excellent clays from two similar deposits, of which the better known is at Clay Bank, about 13 miles south of Red Wing. A careful study of the deposit at Clay Bank long ago led Sardeson [1] to conclude that it represents a remarkable example of the transportation of a large mass of bedrock formations by glacial ice. The clay as opened in the pits is underlain by gravelly drift and the stratification is considerably disturbed, crumpled, and irregular. (See Pl. XIV.) The usable clays are separated by layers of sand and sandy clays and must be carefully sorted out. For a long time several grades were shipped from the pit, some of which were used for sewer pipe and the rest for stoneware, but as

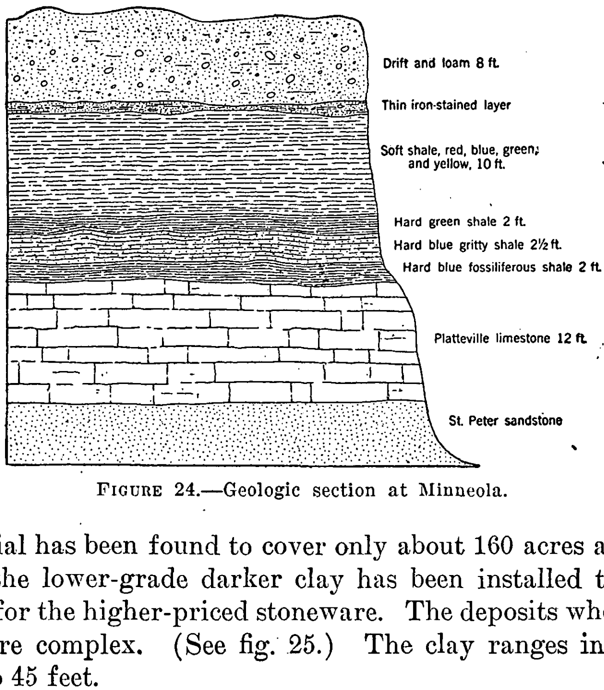


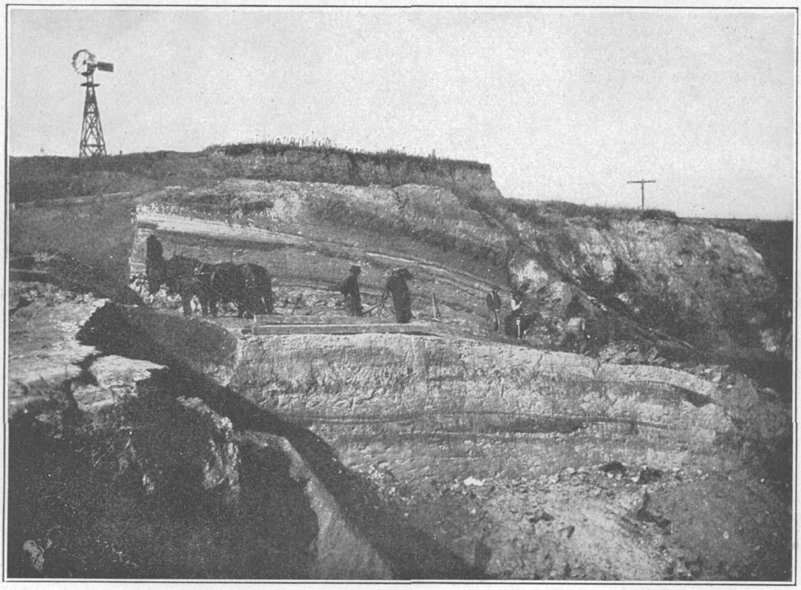
FIGURE 24.—Geologic section at Minneola.

the material has been found to cover only about 160 acres a plant for washing the lower-grade darker clay has been installed to make it available for the higher-priced stoneware. The deposits where locally exposed are complex. (See fig. 25.) The clay ranges in thickness from 10 to 45 feet.

The Red Wing Union Stoneware Co. has produced stoneware since 1872 and now uses 75 tons of clay a day. The clay is mined by hand digging in benches and vertical-sided rectangular pits and is loaded directly on the cars for shipment to Red Wing, where it is stored. Several grades are recognized, some of which are so pure as to require no preliminary treatment. In general, the darker clays are the more impure.

[1] Sardeson, F. W., The so-called Cretaceous deposits in southeastern Minnesota: Jour. Geology, vol. 6, p. 679, 1898.

A.



B.

DISTURBED CRETACEOUS CLAYS AT CLAY BANK, NEAR RED WING.

MOLDED STONEWARE AT RED WING.

The bulk of the clay for the manufacture of stoneware is washed to remove sand and other impurities. It is reduced to a slush in blunger mills, passed through rotary sieves or lawns (80-mesh), and 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 at the boiling point to facilitate the washing and pressing. The coarser sand and impurities are removed in rotary sieves or sifters. The slush is then pumped into large filter presses, where the water is squeezed out and the clay is pressed into cakes weighing about 40 pounds each, which are sent to the mill room and tempered in pug mills. The clay is then loaded on small trucks and distributed to the molders. 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 ready for the kilns. (See Pl. XV.) Slip glazes are imported from Albany, N. Y., and from Michigan, but some Minnesota clays have very similar properties. The ware is burned at a temperature of about 2,200° F., and the heat is maintained from 45 to 60 hours, the time depending upon the product desired. About nine days is required to convert the raw clay into the finished product.

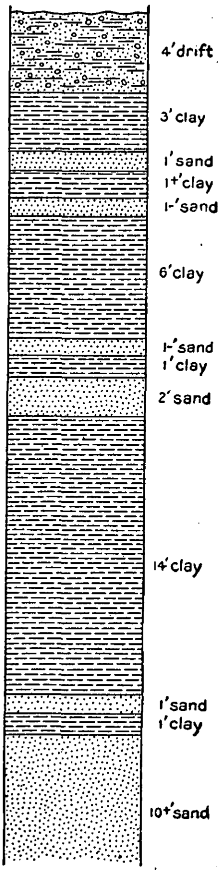


FIGURE 25.—Geologic section at Clay Bank.

The average clay slakes in three minutes, has a fairly high plasticity, and requires 34 per cent of water for molding. It has a tensile strength of about 100 pounds to the square inch, whether dried rapidly or slowly. The shrinkage on drying is about 7 per cent. The best selected clay has a range of vitrification from cone 04 (1,958° F.) to cone 20 (2,786° F.). At all temperatures in this range the products are very hard, the absorption decreasing from about 15 to 3 per cent and the porosity from 28 to 6 per cent. The colors are cream and buff, changing to gray. Fire shrinkage increases very gradually to 7 per cent. Some grades of the material are less refractory—for instance, a dark-blue layer that occurs in small amounts and is used for sewer pipe or is mixed in small proportions with the stoneware clay for large jars.

The stoneware clay is most abundant at Clay Bank, but as mined it contains some impurity and most of it is now washed at Red Wing. The following analyses, as well as the appearance of the coarse sand from the mechanical analysis, indicate that washing eliminates a number of ferruginous concretions and some sand and scales of mica. Several other analyses are reported on page 90.

Analyses of materials from Red Wing.

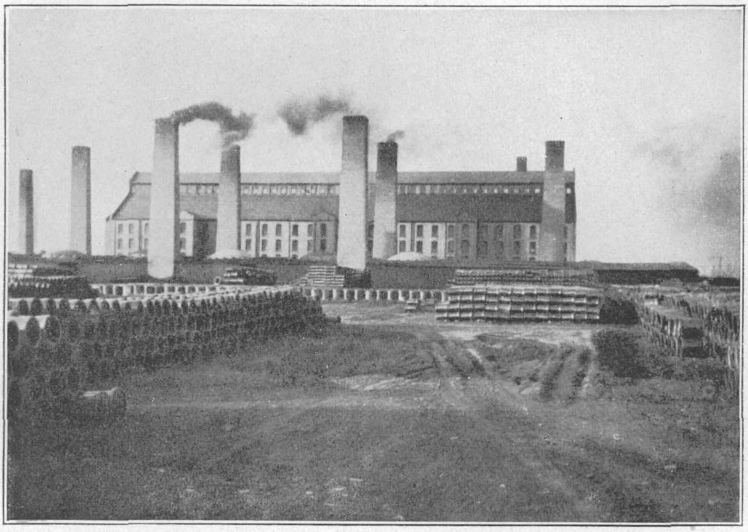
[F. F. Grout, analyst.]

Chemical analyses.	1	2	3	Mechanical analysis (sample 1)	
Silica	69.92	69.26	64.98	Fine clay	26.7
Alumina	17.39	18.57	11.38	Coarse clay	16.0
Iron oxide	1.68	1.93	12.03	Silt	49.8
Magnesia	1.11	.62	2.51	Fine sand	6.5
Lime	.60	.45	.68	Coarse sand	1.0
Soda	.07	.06	.00		
Potash	2.25	2.41	1.93		100.0
Ignition	5.45	5.58	5.28		
Moisture	1.10	1.10	1.08		
Titanium oxide	.63	.77	.71		
	100.20	100.75	100.58		

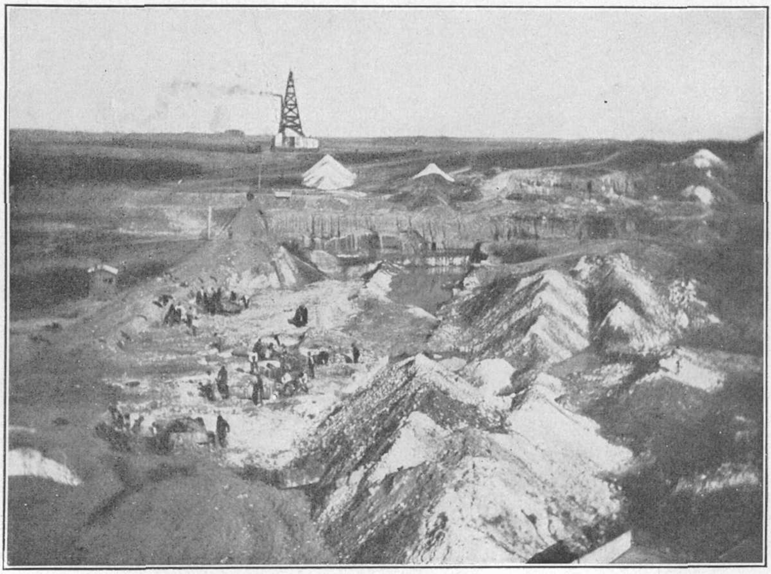
1. Clay as shipped to the stoneware plant, ready for washing.
2. Washed clay; sampled at the plant.
3. Refuse of washing; sampled at the plant.

The Red Wing Sewer Pipe Co., which has plants at Red Wing and Hopkins (see Pl. XVI, *A*), uses Cretaceous clays from a deposit half a mile east of Belle Chester, Goodhue County, as well as the darker clays from Clay Bank. The deposit at Belle Chester (Pl. XVI, *B*) has been discovered much more recently than that at Clay Bank, and its successful development may be taken as an indication that still other deposits of similar excellent clay may yet be brought to light. It was discovered by careful prospecting and observation of fragments in the drift, followed by careful drilling before any excavation was undertaken. It ranges from 1 to 30 feet in thickness (average 10 feet) over 40 acres. Its appearance is so similar to that of the deposit at Clay Bank that its origin is assumed to be the same. The deposit is capped by 3 to 6 inches of ferruginous sandstone and is underlain by a similar sand rock that is apparently of Cretaceous age, though its crumpled condition would seem to indicate transportation by glacial ice. (See Pl. XVI, *A*, and fig. 26.)

Some of the clay at Belle Chester, though a smaller proportion than at Clay Bank, is suitable for use in stoneware or can be washed to make it suitable. It has exactly the same behavior as to stoneware clay described above. The sewer-pipe clay, which is more abundant, is also similar, as shown by the results given below. It slakes in three minutes, has good plasticity with 27 per cent of water, shrinks 8 per cent on drying, and has a tensile strength of over 100 pounds to the square inch.



A. SEWER-PIPE PLANT AT MINNEAPOLIS.



B. CLAY PIT AT BELLE CHESTER.

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
010	Cream	1	15
06	....do	2	12
02	Buff	3	9
3	....do	4	7
6	Gray	6	4
10	....do	7	....

The clay is hard after burning to any of the temperatures specified and reaches viscosity at about cone 10 (2,426° F.), or a little higher in some samples. Though the point of viscosity is usually lower than that of the stoneware clay the range of fusion is very great and the product is excellent. A greenish efflorescence noted on one Belle Chester sample would probably not injure sewer pipe, which is salt glazed.

The company manufactures, in addition to sewer pipe, a few vitrified draintile and other specialties. Its capacity is 35,000 carloads a year. The quality of such products as are made at Red Wing and such clay as is obtained there is best judged by the excellent reputation of the ware.

Although the deposits at Clay Bank and Belle Chester are the only ones of their quality now known in Minnesota, traces of such clay are numerous in the form of fragments, streaks, pockets, and thin lenses in the drift. Many "ironstone" fragments similar to the ferruginous shale layers associated with the clays at Clay Bank and Belle Chester are also found in the drift. These indications seem to be most numerous northwest of the deposits now being worked; and 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.

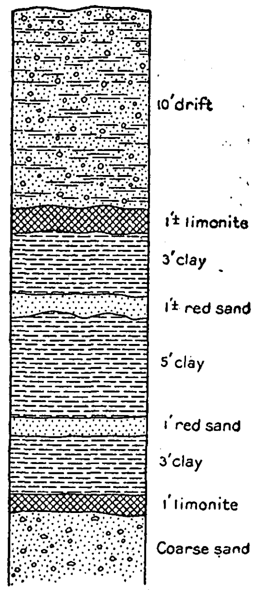


FIGURE 26.—Geologic section at Belle Chester.

OTHER BRICK MATERIALS.

A deposit of gray drift has been explored by the Red Wing Sewer Pipe Co., near Goodhue, in sec. 10, T. 111 N., R. 15 W., in the hope that it will be available as a plastic bond for mixing with the less plastic Cretaceous sewer-pipe clay. The deposit is 20 feet thick and covers 80 acres. It is dark brown to yellowish and is covered by 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 mainly of débris from Cretaceous deposits over which the ice passed. The clay slakes in one minute, is very highly plastic, and requires 26 per cent of water for molding. The tensile strength is well above 50 pounds to the square inch but is considerably lessened by rapid drying. This clay would have a good effect in increasing the strength of a less plastic sewer-pipe clay. Its air shrinkage is 9 per cent. Burning tests by the Minnesota School of Mines experiment station resulted as follows:

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

The clay burns hard at cone 07 (1,850° F.) and becomes viscous at about cone 8 (2,354° F.). Having thus a range of vitrification of 500° it would seem available for making vitrified ware, such as sewer pipe, but some preliminary experiments by the Red Wing Sewer Pipe Co. have resulted rather unfavorably. Its cracking and shrinkage on drying are probably serious defects. The United States Bureau of Standards reports very favorably on a mixture of two-thirds Cretaceous sandy clay and one-third gray drift, stating that the mixture behaves better both in working and in burning than either clay alone.

At the town of Pine Island the loess is exposed over a very large territory to a depth of 5 or 10 feet. The deposit was worked up to about 1909 and produced a fair quality of red brick. The local demand is not great. (See also fig. 9, p. 99.)

Ten miles from Vasa, along Belle Creek, a sandy alluvial clay is rather favorably exposed but is apparently too sandy to make good brick. Some brick were made here about 50 years ago and 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.

At Frontenac John Bartrom owns a deposit of alluvium along Wells Creek. It is not known to be over 4 feet thick and is a considerable distance from the railroad. An analysis made for Mr. Bartrom by F. F. Grout is as follows:

Analysis of alluvial clay from Frontenac.

Silica	63. 32
Alumina	12. 68
Iron oxides	2. 66
Lime	5. 08
Magnesia	3. 94
Moisture	1. 83
Loss on ignition	8. 47
Alkalies, etc., by difference	2. 02

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

GRANT COUNTY.

Clay-bearing formations { Recent: Lake clays. Pleistocene: Gray drift.

Gray drift covers most of Grant County. An attempt made to use it at Elbow Lake was not very successful on account of the common trouble with limestone pebbles. Some laminated clays along the shores of Pelican Lake may be worthy of development.

HENNEPIN COUNTY.

Clay-bearing formations {
Recent: Alluvium.
Pleistocene:
Gray laminated clays.
Red and gray drift.
Ordovician: Decorah shale.

On the north side of Minneapolis the glacial river clays have been utilized in making cream-colored brick, pottery, and fireproofing. An abundant supply still remains, but the value of city property tends to crowd brick works northward into Anoka County. (See pp. 113–115 for a description of the clays.) Similar clay occurs on the southeast side of Minneapolis but is deeply covered with drift. The pebbly gray drift of Hennepin County and recent alluvium along Mississippi River can not well compete with this deposit, nor can the red drift, which is in some places deeply eroded. Swamp clay was used at Hanover, and gray drift was once used at Rogers, but not successfully. The Decorah shale is mostly eroded, is partly buried, and occurs on property more valuable for building than for the manufacture of clay products.

Attention should be called to the sand-lime brick factories at Minneapolis.

HOUSTON COUNTY.

Clay-bearing formations {
Pleistocene: Loess.
Ordovician: Decorah shale.
Cambrian: Shale of St. Lawrence formation.

The shales of the St. Lawrence formation crop out in many bluffs in Houston County but have no value at present.

The Decorah shale occurs in the extreme southwest corner of the county. It can be best developed in the vicinity of Spring Grove, where it is well exposed but is not very thick. A mantle of loess covers most of the county.

No brickyards are now in operation in Houston County, but in former years there were plants at Money Creek, Spring Grove, La

Crescent, Houston, and most other towns in the county. Common red brick can be made from the loess nearly anywhere. (See fig. 9.)

HUBBARD COUNTY.

Clay-bearing formations { Recent: Lake clays. Pleistocene: Gray drift.

About 1½ miles from the Great Northern Railway near Akeley a plant has been operating on a lake deposit which is known to extend over 80 acres to a depth of 40 feet and which may be at least partly of glacial age. The upper half of the deposit is yellow and the lower half blue-gray. Both portions, except a few inches at the top from which the lime has been leached, burn to cream-colored brick. At the plant the production is about 200,000 stiff-mud cream-colored brick a year.

Gray drift was once used for brick 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 bad times.

ISANTI COUNTY.

Clay-bearing formations { Pleistocene: Gray laminated clays. Gray drift.

At Cambridge and elsewhere along Rum River gray laminated clay was used for many years, beginning in 1881. The clay is exposed for 20 feet but is overlaid in the bluff by about 25 feet of sand. It could be profitably worked in only a small area, in which the overlying sand has been at least partly 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. Burning tests resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
05	Salmon	0	24
03	do	2	22
01	do	3	18
2	Greenish brown	5	5
3	do		

The brick were too hard to be scratched with a knife after burning to cone 04 (1,958° F.), and they reached viscosity at cone 3 (2,174° F.) The addition of 50 per cent of sand to the clay increases the range of vitrification and seems to improve the general character as brick material. The brick produced were equally good. A small plant made salmon-colored brick from this clay by using a high proportion of the overlying sand, but work has been abandoned.

One or two attempts to use the gray drift without removing the limestone pebbles met with the usual difficulty.

ITASCA COUNTY.

Clay-bearing formations:
- Recent: Lake clays.
- Pleistocene:
  - Gray laminated clay.
  - Gray drift.
  - Red drift.
- Huronian: Paint rock, etc.

No clays were worked in Itasca County up to 1900, but since that year the development of the iron ranges has led to several attempts at brick-making. Brickyards were started to utilize gray laminated clays at Grand Rapids and Verna. A sand-lime brick plant at Pengilly is a competitor of the clay-brick industry.

The Verna Brick Co. is developing the deposit at Verna, near Warba station on the Great Northern Railway. The portion of the deposit that is considered available is about 10 feet thick and extends over about 10 acres. It is yellowish gray in color and has apparently been leached. Underlying it and extending over a great many acres of the surrounding country is a blue laminated clay containing a few limestone concretions. The gray clay burns cream-colored and the blue clay is said to burn red and to show a much greater shrinkage. Any attempt to mix the blue and gray clays encounters the difficulty common to all attempts at mixing a stiff, plastic clay with a lean, sandier clay. The plastic lumps remain suspended in the more fluid mass and require very thorough pugging or some other form of mixing to get a satisfactory structure and avoid auger laminations. The yellowish-gray 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 to the square inch, even after rapid drying. As burned at the Minnesota School of Mines experiment station it gave the following results:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
03	Buff	1	30
01	....do	4	23
2	Greenish buff	12	5
3	....do	....	....

The clay becomes hard at cone 02 (2,030° F.) and reaches viscosity at cone 3 (2,174° F.). The plant has a capacity of 35,000 brick a day and makes a common brick of cream color, using wood as a fuel.

At Grand Rapids bricks were burned from a lean, very sandy laminated clay that lies along the banks of a small creek at the northeast edge of town. The clay is yellow and seems to be very sandy when dry. It slakes in one minute and has very low plasticity, requiring 21 per cent of water for molding. Its shrinkage is 3 per cent on drying. Its tensile strength is over 130 pounds to the square inch, but the adhesion test indicates that it would not work well in an auger machine. As burned at the Minnesota School of Mines experiment station it gave the following results:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
03	Red	1	21
1	Brown	4	13
3	.....do	5	10
5	.....do	....	....

The clay burns too hard to be scratched by a knife at cone 02 (2,030° F.) and becomes viscous at cone 5 (2,246° F.). Two attempts at brickmaking were made by soft-mud methods and one by a stiff-mud machine. None were particularly successful, and work has ceased. Shipping facilities are not very favorable.

Cretaceous shales were reported by Grant[1] to occur on Deer River near its mouth. River erosion had removed the overlying glacial drift and left the shales with a smooth, polished surface that resisted erosion much more successfully than the drift. Limy concretions have generally been considered rare in the Cretaceous deposits, but a trip through the Deer River neighborhood revealed no outcrops that did not contain a rather large number of lime concretions or pebbles. The clays are probably of Pleistocene age.

On Bigfork River, 2 miles below the mouth of Deer River, blue clay crops out near water level. It is sticky and tough but is so inaccessible and so covered with water as to be unprofitable. A similar outcrop occurs on Bigfork River, 2 miles above the mouth of Deer River.

On Deer River, half a mile above the mouth, 4 to 6 feet of apparently good clay crops out for 50 feet along the bank and is probably continuous with another outcrop close to the mouth of the river. The clay is laminated with alternate light and dark blue layers. It is covered by about 10 feet of glacial drift and contains a few rounded pebbles. The deposit is somewhat more accessible than those on Bigfork River mentioned above and is perhaps the most promising clay discovered in this region. The clay slakes in two minutes and shows medium plasticity with 33 per cent of water. Its tensile strength is 100 pounds to the square inch and it shrinks 9 per cent on drying. A burning test by the Minnesota School of Mines experiment station resulted as follows:

[1] Grant, U. S., Geology of Minnesota: Minnesota Geol. and Nat. Hist. Survey Final Rept., vol. 4, p. 183, 1899.

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
010	Salmon	1	16
04	.....do	4	12
02	Red brown	11	1
2	.....do	13	0

This clay has to be heated slowly and oxidized or it will develop black cores and fail at very low temperatures.

The mantle of gray drift over the county is largely modified by the action of water and is sandy, but its surface is irregular and contains many lakes. Clays have accumulated in these lake basins, probably beginning in glacial time but continuing to the present. 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

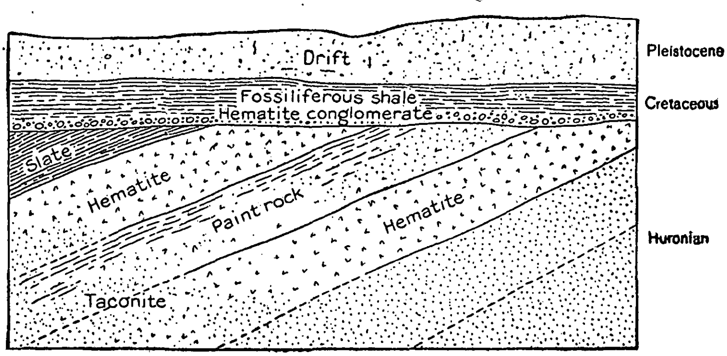


FIGURE 27.—Geologic section at Coleraine.

slakes in three minutes and shows fairly high plasticity, requiring 28 per cent of water for molding. Its air shrinkage is 7 per cent, and it checks considerably unless carefully dried, so that its tensile strength ranges from 50 to 150 pounds to the square inch. Burning tests gave the following results:

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

The clay becomes hard at cone 05 (1,922° F.) and reaches viscosity at cone 2 (2,138° F.).

At Coleraine the "paint rock" of the iron-ore formation is over 20 feet thick and is especially troublesome in the mines. (See fig. 27.) 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 could be used for red brick, though it could not be safely vitrified. It slakes promptly and is plastic with 27 per cent of water. Its air shrinkage is small. Brick made from it do not become thoroughly hard below a temperature of cone 4 (2,210° F.). An analysis is given in the report on St. Louis County (pp. 225–230).

At Pengilly, where a particularly sandy phase of modified drift extends over a large area, a sand-lime brick plant has recently been erected. It has every chance of success if the product is kept up to the high grade possible.

JACKSON COUNTY.

Clay-bearing formations
- Recent:
  - Lake clay.
  - Alluvium.
- Pleistocene:
  - Gray drift.

Brick and tile are manufactured from gray drift at Jackson, where 15 feet of yellow clay, with very little limestone or other impurities, extends over an area of 14 acres. The deposit is close to the Chicago, Milwaukee & St. Paul Railway, and conditions seem to be favorable for the development of a considerable industry. This plant has used the dry process of separating limestone from the clay. The pit is kept dry and the clay is plowed over a considerable surface and gathered up only after the wind and sun have dried it 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. When pebbles accumulate in the dry pan it is stopped and cleaned out. Lack of shed room limits the capacity and output of the plant.

At Okabena similar gray drift has been used in two small plants to make hand-molded brick.

The nature of the gray drift of Jackson County is indicated by the following tests. The clay slakes in two minutes and is highly plastic, with 29 per cent of water. It shrinks 6 per cent on drying and develops a tensile strength of 125 pounds to the square inch. Burning tests gave the results set forth below:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
04	Salmon	2	25
02	Buff	3	22
01	....do	5	14
1	Greenish buff	8	6
2	....do	10	1

The clay is too hard to scratch with a knife after burning to cone 02 (2,030° F.) and reaches viscosity at cone 2 (2,138° F.). If the limestone pebbles are not removed most of the burned products slake after exposure; if they are removed good brick are produced.

River alluvium, known to be 5 feet thick, occurs at Jackson over about 20 acres along the flood plain and is said to overlie blue clay. It was developed about six years ago. The product, consisting of red brick, was used in several buildings in Jackson. The clay seems to work and burn well, but it contains a few limestone pebbles, which have caused difficulties.

A gentle slope of about 100 acres on the shore of Heron Lake is underlain by 12 feet of yellow laminated clay, probably in part of glacial origin and in part recent. The laminae are of variable thickness, and many of the vertical joints are stained with iron. The deposit is surrounded on all sides by pebbly gray drift, except along the lake. Bleininger[1] says:

A glacial calcareous clay from Heron Lake, Minn., possessing good plasticity and working properties, though somewhat too fine grained for drying when made into larger pieces.

Specific gravity, powdered dry clay = 2.654.

Linear shrinkage, in per cent of wet length = 7.72.

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.

This sample was evidently not suited to yield such data as were hoped by experiments in preheating, as the raw clay showed no more cracking than the preheated clay and was as good as the others after preheating. The effect of preheating on fineness of grain explains some of the variation found in plasticity and shrinkage.

The tensile strength of the clay is 150 pounds to the square inch, and the shrinkage on drying is 5 per cent. Burning tests resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
04	Buff	2	30
02	do	5	23
01	do	7	19
2	Greenish buff	13	1

The clay is hard after burning to cone 04 (1,958° F.) and reaches viscosity at cone 2 (2,138° F.). The following analysis is available:

Mechanical analysis of clay from Heron Lake.

Fine clay	9.3
Coarse clay	16.8
Silt	69.4
Fine sand	4.1
Coarse sand	.4
	100.0

[a] Bleininger, A. V., Effect of heat treatment upon drying of clays: Bur. Standards Bull. 7, No. 2, 1911.

A company at Heron Lake has been at work since 1890 producing hollow brick and title in a number of downdraft kilns with a capacity of about 80,000 a day. The product is cream-colored if burned hard and salmon-colored at lower temperatures. The clay is more suitable for hollow brick and tile than for any other products. The fusion is so sudden that the products are seldom vitrified.

KANABEC COUNTY.

Clay-bearing formations:
- Pleistocene:
  - Gray laminated clay.
  - Red drift.
- Algonkian (?): Red clastic series.

At Mora an attempt was made years ago to use the shales of the red clastic series for terra cotta. These shales are hard and red and occur at several horizons in the sandstone formation. Wells show that the clay has considerable areal extent below the drift and that its thickness is as a rule not over 10 feet. In sec. 1, T. 39 N., R. 24 W., near Mora, a 3-foot bed is visible along the river for about 100 yards. An attempt was made also to use the ferruginous shaly sandstone near by, but as now exposed it contains very little clay and has no strength at all. The clay slakes in two minutes and is very plastic, requiring 22 per cent of water for molding. Its air shrinkage is 5 per cent. Burning tests resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
06	Red	0	17
03	do	1	16
2	do	2	14
5	do	3	12
12			Melted.

The clay becomes hard at cone 06 (1,886° F.) and reaches viscosity at about cone 8 (2,354° F.). The range of vitrification is over 400° F., and if a large body is discovered it should make excellent products.

Yellow laminated clays crop out in the bank of the river at the northwest side of Mora. The deposit apparently extends over many acres and was sampled to a depth of 6 feet without reaching the bottom. It appears to contain rather numerous limy concretions, and its quality was not good. Its shrinkage on drying, for example, was over 19 per cent, and on burning it checked, formed black cores, and showed still further shrinkage. Its successful use would require extreme care. 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. At one point at least—just east of Rice Creek on the road from Brunswick to Grasston—laminated lake clays, including some sandy layers 6 inches thick, were used. The clay slaked at once, was fairly plastic, and had an air shrinkage of 8 per cent. Burning tests resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
05	Salmon	1	23
03	.....do	3	20
01	.....do	7	5
1	Brown	9	2
2	.....do	....	....

The clay is hard after burning to cone 05 (1,922° F.) and reaches viscosity at cone 2 (2,138° F.). Favorable shipping facilities are lacking, but if the local market were good this clay deposit might again be used.

A similar deposit is reported near the station at Grasston, but only gray drift is now exposed.

KANDIYOHI COUNTY.

Clay-bearing formations { Pleistocene: Gray laminated clay. Gray drift.

The laminated clays are the chief clay resources of Kandiyohi County, though gray drift is abundant. A little over a mile west of Willmar, along the Great Northern Railway, is a deposit of laminated clay known to extend over about 25 acres. It consists of 15 feet of yellow oxidized material underlain by at least as much blue clay. The yellow clay contains 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 burn cream-colored at high temperatures but salmon-colored if underburned. The Willmar Brick Co. has been at work here for 20 years, making about 2,000,000 stiff-mud cream-colored brick and some draintile each season. Another plant on the northwest side of Nest Lake used similar clay for some time.

Kandiyohi County contains many lakes and marshes, some of which may be underlain by alluvial clays.

KITTSON COUNTY.

Kittson County is no doubt supplied with clay like that used at Grand Forks and Winnipeg—the silts of the Red River valley. Well records report clay to a depth of 136 feet, and it is no doubt usable to as great a depth as at Grand Forks.

KOOCHICHING COUNTY.

Clay-bearing formations
- Recent: Alluvium.
- Pleistocene:
  - Gray laminated clay.
  - Silt of the Red River valley.
  - Gray and red drift.
- Cretaceous (?): Shales (?).

The erosive action of the waves of Lake Agassiz and of streams and the deposition of eroded material in the lake have left Koochiching County flat and largely swampy. Clays occur in some of the swamps, but in few places are they of good quality. Where streams have cut through this surface material other types of clay are exposed, of which the Cretaceous shales are of doubtful identity and the red drift is not prominent because buried under later gray drift and laminated clay and still later modified by Lake Agassiz. The laminated clays are the most valuable for clay products.

The surface material is apparently very uniform. Its quality is shown by samples taken near International Falls, where it is found to be a sticky clay to a depth of 40 feet. Its upper part is leached and to a depth of 6 feet is relatively pure, but below that limestone pebbles and concretions are numerous. Clay of this type is easily accessible eastward from the town, toward the "French settlement," and probably elsewhere. The clay slakes in two minutes and shows a very high plasticity, requiring 29 per cent of water for molding. Its air shrinkage is 9 per cent, and it probably shows considerable tendency to crack on drying. If drying is done slowly and with care the tensile strength is nearly 200 pounds to the square inch, but with rapid drying the strength is below 50 pounds to the square inch. A burning test resulted very much like that on the gray drift full of limestone pebbles (see pp. 55–56), indicating that this coarser limy gravel must be removed 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, and it is doubtful if the process used at that place will apply with equal success to the clay near International Falls. The success of the Hutchinson process depends not only on the removal of limestone, but on the quality and the mixing of the materials left. The percentage of lime in this clay is much the same as in the drift (7.5 per cent as compared with 9 per cent), and the essential clay substance shows the same behavior in the fire. But the gray drift contains approximately 30 per cent of sand that would be caught in the 100-mesh sieve, and the clay in the Lake Agassiz basin contains only about 3 per cent of sand. Sand is not abundant anywhere in the neighborhood, and it is suggested that those who wish to use the clay should grind rather than wash it.

The details of the vitrification of one sample of the leached upper clay are as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
06	Salmon	1	19
03	....do	3	15
02	Red	9	3
1	Brown	9	2
3	....do	10	1

The clay is hard after heating to cone 03 (1,994° F.) and reaches viscosity at cone 3 (2,174° F.). It requires slow, careful oxidation to avoid black cores.

A small creek at the west edge of Big Falls has cut into irregular layers of sand and clay, which overlie the usual pebbly drift of the region and which may be partly leached drift and partly alluvium. If the deposit is as extensive along the creek as it seems to be it might furnish a local brick supply. The clay slakes in one minute, is highly plastic, and requires 20 per cent of water for molding. Its tensile strength is well above 200 pounds to the square inch, even when rapidly dried. Its air shrinkage is 4½ per cent. As burned at the Minnesota School of Mines experiment station, it gave the following results:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
02	Salmon	1	18
01	....do	1	17
2	Chocolate	4	11
3	....do	5	7
4	....do	6	2

The clay becomes hard at cone 02 (2,030° F.) and viscous at cone 4 (2,210° F.). The range of vitrification is therefore over 150°, and it can safely be burned hard.

The best clays in Koochiching County have not been found at easily accessible points. Several steep clay banks along Bigfork and Littlefork rivers have exposed laminated clays or shales of a type not exactly duplicated anywhere else in Minnesota. From their location it is supposed that they correspond to the patches formerly mapped as Cretaceous. However, some of them rest on glaciated rock surfaces and hence are now classed as postglacial or interglacial. Though they differ from the glacial clays of the neighborhood in containing no limestone pebbles, they are very much like the laminated glacial clays farther south at Wrenshall. In their behavior in firing and in their chemical composition they also resemble glacial clays much more closely than Cretaceous shales.

At Big Falls, southwest of International Falls, Bigfork River has cut a rather extensive gorge below the falls from which the town is named. The bluffs in most of the gorge reveal a blue clay weathered to yellow near the surface and containing numerous limestone pebbles; but a little below the mouth of Sturgeon River, on the farm of Ben Lind, there is an outcrop showing a clay of different type. The section is as follows:

Section on Bigfork River below Sturgeon River.

	Feet.
Soil	1
Common pebbly clay of the Lake Agassiz Basin	10
Plastic yellowish-gray clay	10
Very fine sandy clay	30

The clay crops out for several hundred yards along the bluff and represents a large deposit, though somewhat inaccessible in the present state of development of the country. The plastic yellowish-gray clay of the section slakes at once, shows medium plasticity, and requires 28 per cent of water for molding. Its tensile strength is over 150 pounds to the square inch, even when rapidly dried, and its air shrinkage is 3 per cent. Burning tests resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
03	Cream	1	31
02	Buff	3	26
1	do	9	14
3	do		

The clay is hard after burning to cone 02 (2,030° F.) and reaches viscosity at cone 3 (2,174° F.). The working and burning qualities of the clay are not injured by the addition of a large proportion of the surface silt, but if all layers are mixed the proportion of sandy clay is too great. The overburden of clay, 10 feet thick, is no more valuable than the clay found nearly everywhere through the county.

Still more difficult of access in the banks of Littlefork River, several miles east of Big Falls, are some exposures of a nearly white, smooth clay, which crops out at intervals for miles. The clay is slightly laminated with alternating white and light blue-gray layers about 1 inch thick and has no visible impurities.

Clays of somewhat darker gray crop out in places farther up Littlefork River and probably for some distance up Bigfork River. The outcrop in this county closest to transportation lines is on Littlefork River at the boundary between St. Louis and Koochiching counties. A few similar outcrops still farther east in St. Louis County are close to the station at Cook and are more accessible.

Samples taken at the head of Net Lake Rapids and for a few miles down the river, in secs. 36 and 26, T. 64 N., R. 23 W., in sec. 1, T. 64 N., R. 24 W., and in sec. 15, T. 65 N., R. 24 W., are fairly uniform in general character. Only the sample from the most northern locality burned red, and this was taken at water level and was probably leached.

All these laminated clays slake in a few minutes and develop fairly high plasticity. The shrinkage on drying is 5 to 8 per cent, and the tensile strength is 150 to 200 pounds to the square inch. The following results of burning tests are representative of the blue-gray laminated clay below Net Lake Rapids:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
05	Cream	0	23
04	....do	1	22
02	Buff	7	10
2	....do	9	4
3	....do	10	1

The clay is hard after burning to cone 05 (1,922° F.) and reaches viscosity at cone 3 (2,174° F.), having thus a range of 250° F. This clay was analyzed by A. W. Gauger, with the following result:

Analysis of laminated clay from Koochiching County.

Silica	47.70
Alumina	13.58
Iron oxides	6.51
Magnesia	3.13
Lime	11.70
Soda	1.05
Potash	2.34
Loss on ignition	13.23
Moisture	1.79
Titanium oxide	.31
	101.34

A similar clay from the head of Net Lake Rapids gave the following results of burning tests:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
04	Buff	1	23
03	....do	4	13
02	....do	8	6
2	....do	9	5

The clay is hard after burning to cone 03 (1,994° F.) and reaches viscosity at cone 4 (2,210° F.). At the bottom of the exposure the beds are more sandy, but a mixture of the whole bank gave results almost identical with those just reported. This clay was exceptional in containing a number of calcareous concretions. (See Pl. II, *D*, p. 36.) It is of interest and may be a matter of some importance that pottery is found along Littlefork River in such situations as to indicate that the Indians made use of these laminated clays.

The outcrop in sec. 1, T. 64 N., R. 24 W., is exposed by a series of landslides along the steep banks of the river. The unusually light-colored clay is very smooth and plastic. Outcrops are most numerous between two small creeks that enter the river from the south. Burning tests of this clay resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
06	Buff	0	23
02	.....do	1	20
01	.....do	2	20
2	.....do	4	18
5	.....do	8	1

The clay is hard after burning to cone 02 (2,030° F.) and reaches viscosity at cone 5 (2,246° F.).

The only red-burning laminated clay was the weathered sample from sec. 15, T. 65 N., R. 24 W., which gave the following results:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
06	Red	0	17
03	.....do	2	13
01	.....do	4	10
2	Brown	5	5
3	.....do	5	2
5	.....do	6	....

The clay is hard after burning to cone 06 (1,886° F.) and reaches viscosity a little above cone 3 (2,174° F.), with a fairly slow decrease in porosity.

LAC QUI PARLE COUNTY.

Clay-bearing formations { Pleistocene: Gray drift.
Cretaceous: Shales.
Archean: Residual clay.

Gray drift, somewhat modified by leaching near the surface, covers Lac qui Parle County, and the Cretaceous shales and Archean clay are found only in wells. At and southwest of Dawson white clay having the appearance of the Archean is found at a depth of 160 feet.

LAKE COUNTY.

Lake County contains red drift and associated lake clays, but they have not been used. Possibly swamp deposits occur. The Keweenawan shows thin shale lenses of no value.

The red clay resembles the red clay of Lake Duluth. (See Carlton County, pp. 134–140.) No samples are available except one sent in from Beaver Falls, which shows the extremely high shrinkage characteristic of the type. The clay slakes in three minutes, and when the extreme amount of 55 per cent of water is added it remains stiff and of good molding consistency. It has an air shrinkage of 13 per cent and is likely to crack. It develops a tensile strength of over 100 pounds to the square inch if carefully dried. Burning tests show that a further high shrinkage occurs. The volume of well-vitrified bricks is less than 35 per cent of the volume as molded wet. The results of the tests were as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
010	Salmon	5	25
06	....do	6	23
04	Red	10	15
02	....do	19	2
01	....do	.....	.....

The clay is hard after being burned to cone 010 (1,742° F.) and reaches viscosity at cone 01 (2,066° F.). The great fire shrinkage results in a tendency to crack, but the range of vitrification is good (300° F.) and the clay may be valuable as a plastic bond or a slip clay.

The following analysis, made by J. A. Dodge, represents a shaly sand rock half a mile below the first falls of Baptism River, which is thought to be of Keweenawan age:[1]

Analysis of shaly sand rock from Lake County.

Silica	66.72
Alumina	7.41
Ferric oxide	10.13
Ferrous oxide	.69
Magnesia	4.06
Lime	3.10
Soda	.86
Potash	.42
Loss on ignition	5.32
	98.71

LE SUEUR COUNTY.

Clay-bearing formations:
- Recent: Alluvium and swamp clay.
- Pleistocene: Gray drift.
- Cretaceous: Shale.

In Le Sueur County interest centers in a refractory clay near Ottawa, though clays of other types have been used at several places

[1] Minnesota Geol. and Nat. Hist. Survey Thirteenth Ann. Rept., p. 100, 1885.

for common brick. The most promising occurrence near Ottawa is a shale deposit that was developed a little over half a mile up Cherry Creek and half a mile from the Chicago & Northwestern Railway. Mr. Randall, on whose farm the clay occurs, reports that it was tested to a depth of 27 feet without reaching the bottom. It underlies an unknown area of the high prairie east of Ottawa. The geologic section is as follows:

Geologic section near Ottawa.

	Feet.
Yellow and gray drift	100
White clay	4
Blue clay	8
White clay	4
Fine white sandy clay.	

This clay crops out in the bed of Cherry Creek, and there might be some difficulty in draining and mining it. It slakes in one minute and is very 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.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
05	Cream	4	20
02	do	5	20
2	do	8	14
4	do	8	14
6	do	10	11
13	Gray	12	6

The clay has a hardness of 6 at cone 05 (1,922° F.), is fully steel hard at a slightly higher temperature, and apparently does not even approach viscosity at cone 13. The Bureau of Standards reported that it behaved like a refractory clay. Although it may prove to be highly refractory it appears to burn dense at moderate temperatures. The analyses available average as follows (see also p. 90):

Average composition of clay near Ottawa.

Silica	56.70
Alumina	28.50
Iron oxides	.18
Magnesia	.23
Lime	.69

The St. Paul Fire Brick Co., organized to exploit this deposit, built a rather extensive plant with dry-pan, wet-pan, and re-press machines, having a capacity of several million brick a year. No products have been turned out for several years. The deposit should be considered for further work.

Another clay near Ottawa lies half a mile below the railroad bridge over Cherry Creek, 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 conformable with the Jordan and the Shakopee but has been washed in during Cretaceous or pre-Cretaceous time. It seems to belong to a type which is widely distributed throughout the Minnesota Valley from Shakopee to New Ulm. (See Blue Earth County, pp. 121–126.) The clays are variegated red, yellow, and white and in many places lie like stratified sediments unconformably over either the Jordan or the Shakopee. Another common occurrence is in large waterworn cavities and fissures.

Before the deposition of these Cretaceous clays the rocks of the Minnesota Valley had been eroded by rivers and other agents into irregular basins, potholes, and hollows 5 to 25 feet in depth, many of them with overhanging walls. These pocket-like cavities are smoothly waterworn. Winchell[1] has described an instructive section of the Shakopee dolomite and its associated deposits of this clay in a cut near the railroad bridge that crosses Blue Earth River about a mile above its mouth.

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 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 occupied 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 the 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.

[1] Winchell, N. H., Minnesota Geol. and Nat. Hist. Survey Second Ann. Rept., p. 178, 1874.

The sample collected at Ottawa slakes in two minutes, is very highly plastic, and requires 31 per cent of water for molding. Its tensile strength is over 100 pounds to the square inch, even when rapidly dried. Its shrinkage on drying is 8 per cent. As burned at the Minnesota School of Mines experiment station it gave the following results:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
010	Red	1	18
06	do	4	14
04	do	7	11
03	do	9	7
1	do	10	4
6	do	10	3

The clay becomes hard below cone 010 (1,742° F.) and viscous at cone 10 (2,426° F.). Its qualities are thus shown to be so excellent that it may be quite worth while to search out more deposits of this character and see if some of them may not be of a size and accessibility to warrant further development.

Half a mile from the Chicago, St. Paul, Minneapolis & Omaha Railway station at Ottawa the river bluffs for a considerable distance expose 50 to 100 feet of gray drift. A few feet of coarse gravelly drift overlies the boulder clay, which was sampled. The clay slakes in three minutes and has low plasticity, requiring 19 per cent of water for molding. Its air shrinkage is 3 per cent, and its tensile strength is nearly 200 pounds to the square inch, though it checks slightly if rapidly dried. The abundant particles of limestone cause disruption of ware burned up to the temperature of cone 2 (2,138° F.), and melting occurs at a temperature a few degrees higher. Before using this material it would be absolutely necessary to remove the limestone pebbles; but it seems worth while to call attention to it, because mixtures of it with the high-grade Cretaceous clays that occur in the same neighborhood would increase the variety of products without greatly increasing the expense or difficulty of manufacture.

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

At Le Sueur the alluvium of Minnesota River is favorably exposed beside the Chicago, St. Paul, Minneapolis & Omaha Railway and is typical of the deposits of the neighborhood. The river flood plain is not exactly level, and the clay is a little richer on the low ground and more sandy on the high ground. It slakes at once, has 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 to the square inch. Burning tests at the Minnesota School of Mines experiment station gave the following results:

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

The clay becomes hard at cone 02 (2,030° F.) and reaches viscosity at cone 3 (2,174° F.) An analysis of this clay is given on page 103, in the discussion of Recent alluvium. The plant here can produce about 10,000 soft-mud red brick a day. These brick have stood the test of service since 1882 in some of the buildings in Le Sueur. The kiln is not down on the flood plain and so escapes the high water which even yet occasionally covers the deposit.

LINCOLN COUNTY.

Gray drift covers the whole of Lincoln County, and is probably not well situated for development, though attempts to use it have been made in a small way in the past. Cretaceous shales are known by well records only.

LYON COUNTY.

Clay-bearing formations { Pleistocene: Gray drift.
Cretaceous: Shales.
Archean: Residuals.

Gray drift covers Lyon County, but attempts to use it without removing its limestone pebbles and concretions have failed. At Marshall, where shipping facilities are good, it might be possible to clean the clay, but the business would meet competition in a well-established concrete block and tile factory.

Cretaceous clays are known from many well records to lie within 50 feet of the surface, but their quality is unknown. Clay shown in a record as "white earth" probably has the character of the basal Cretaceous.

In this county the Archean probably lies too deep for consideration.

McLEOD COUNTY.

The only clays known in McLeod County are in the gray drift, but some recent lake clays may yet be found.

The only brickyard in the county is at Hutchinson, where brick and draintile of excellent quality are manufactured from the ordinary gray drift. The glacial drift here is the same as that found over large sections of the State and is full of lime and quartz pebbles, sand, gravel, and even large boulders. The plant has been successful in the use of this material, with which many others have failed, because of the special washing process devised by M. C. Madsen, whereby the pebbles are completely separated from the clay. This process is of especial importance to all who may be interested in the ceramic industry, because it opens up a field for the utilization of a vast amount of material which has heretofore proved almost valueless. A description of this plant and the methods used is given on pages 55–56.

The gray drift exposed at Hutchinson consists of 16 feet of oxidized yellow clay, underlain by a considerable thickness of clay, blue in color but otherwise similar to the yellow clay. The extent of the deposit is to be measured in scores of square miles. As overburden there is a few inches of soil.

The clay, as used at the plant, slakes in five minutes, is fairly plastic, and requires 24 per cent of water for molding. Its tensile strength is nearly 100 pounds to the square inch and more than 75 pounds to the square inch when rapidly dried. Its shrinkage on drying is 6 per cent. Burning tests resulted as follows:

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

The clay burns too hard to be scratched with a knife at cone 06 (1,886° F.) and becomes viscous at cone 3 (2,174° F), thus having a range of about 300°. It can safely be burned to a hard but somewhat porous product.

A special study has been made as to the exact effects of washing on the nature of the clay. Samples were taken of the clay as dug from the bank, of the washed clay as settled in different parts of the pond, and of the mixture made up from the different settlings for molding into tile. In composition this mixture varies slightly. Analyses of its component clays are given in columns 2, 3, 4, and 5 of the table below. Column 1 gives, for comparison, an analysis of the average drift before washing.

Analyses of clay and washed clay at Hutchinson.

F. F. Grout, analyst.

	1	2	3	4	5
Silica	58.85	70.21	62.60	50.65	50.55
Alumina	7.25	6.27	6.96	9.01	9.41
Iron oxides	4.97	3.16	3.75	5.26	6.19
Magnesia	3.45	1.55	3.59	3.60	3.62
Lime	9.42	7.28	7.78	10.20	10.20
Soda	1.37	2.11	1.94	1.32	1.22
Potash	1.76	1.53	1.82	1.83	1.85
Moisture	} 2.10	.60	1.80	3.40	3.10
Combined water		1.38	2.90	6.10	6.05
Carbon dioxide	11.20	6.00	7.10	8.20	8.00
Titanium oxide	.36	.19	.33	.53	.60
	100.73	100.28	100.57	100.10	100.79

1. Average gray drift.
2–5. Washed gray drift: 2, Coarse sand; 3, fine sand; 4, coarse clay; 5, fine clay.

Samples 2 to 5 were taken at successively greater distances from the inlet of the pond. It is noteworthy that though silica is high in sample 2, indicating a good deal of quartz sand, a notable amount of calcium carbonate is also present. Samples 4 and 5, though taken at different distances from the inlet, are much alike in composition and apparently also in size of grain. The alumina and combined water are higher in this fine clay, indicating more kaolinite, but so also are the iron oxides and calcium carbonate. It appears to the writer that the washing process has been of benefit in the matter of texture rather than in that of composition. The great and essential change is the elimination of the limestone pebbles.

MAHNOMEN COUNTY.

Pleistocene gray drift, with a little more lime and less sand than is usually found in the gray drift, covers Mahnomen County except where recent swamp deposits occur. The swamp deposits may prove to be worth investigation, but such clays are not so abundant as in counties near by.

MARSHALL COUNTY.

The silts of the Red River valley overlie the gray drift in much of Marshall County. North of Warren the clay along the river has been used for many years. It is known to extend over 100 acres. The following is an average section:

General section north of Warren.

	Feet.
Black soil	½
Yellow to brown alluvial clay	4
Pebbly brown alluvial clay	6–10
Yellow-gray stratified sand and gravel	10
Hard blue smooth, plastic clay.	

The upper 4 feet are almost free from pebbles and are used occasionally for making soft-mud cream-colored brick. The underlying blue clay was tested at the plant and reported useless for common brick.

MARTIN COUNTY.

Companies with capital invested have sought for good clay in Martin County, and have offered prizes for its discovery without success. A fine silty clay of doubtful origin, suitable only for hand molding, occurs at Granada. Surface loam was used for brick on the south side of Buffalo Lake, but the product was not of high quality. The rest of the county is covered with gray drift, which is usable only if the limestone pebbles can be economically removed.

A plant at Fairmont formerly used clay from Blue Earth, Faribault County. (See p. 156.)

MEEKER COUNTY.

Clay-bearing formations	Pleistocene: Gray laminated clay. Gray drift.

Near Litchfield and Kingston brickyards were operated for years on some laminated clays that were apparently formed in basins in the ice. Limy concretions occur in layers. The gray drift north and west of Litchfield consists largely of clay but is somewhat pebbly. South of Watkins the gray drift crops out at many places, but would require the usual cleaning treatment before successful use could be made of it. An attempt which did not include the removal of limestone pebbles was a complete failure.

MILLE LACS COUNTY.

Clay-bearing formations	Recent: Lake and swamp clay. Pleistocene: Gray laminated clay. Red drift.

At Brickton, north of Princeton, two or more brick factories are at work upon a deposit of laminated clay, apparently of the common yellow-gray type, which extends across Mille Lacs County in a belt apparently controlled by the position of the glacial ice. Under the soil lies a superficial layer of clay, rarely over 4 feet thick, which has lost its laminated structure and which has apparently been so leached of lime that it burns red. Below this is 10 feet of yellow clay, underlain by 10 feet of gray clay. All these clays are usually worked together, mixed in the same proportion in which they are found. Below the gray clay is a considerable thickness of joint clay, which is reported as being greasy but which cracks too readily on drying to be satisfactorily used. Wells drilled through this joint clay find a water supply in gravel and sand just below it. (See fig. 28.) A few layers of the clays used contain ferruginous and calcareous concretions, but these do not cause much difficulty. As is usual in such deposits, sand occurs throughout in pockets or irregular streaks. The clay in some pits is more suitable for soft-mud than for stiff-mud processes, but the main product is manufactured with stiff-mud machines. A smaller proportion is made light, for fire-proofing, by a central opening. Auger laminations cause considerable difficulty unless the clay is well mixed.

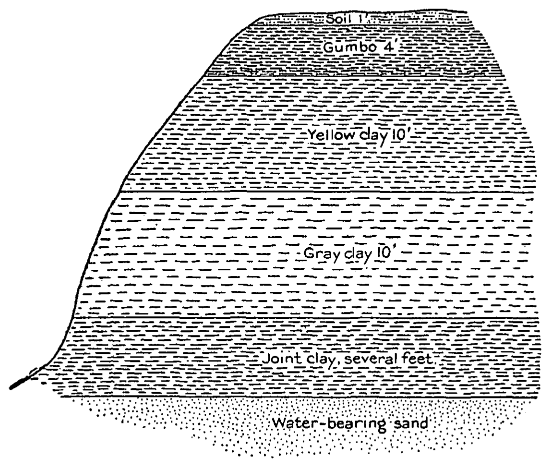


FIGURE 28.—Geologic section at Brickton.

The clay slakes at once and develops only medium or low plasticity requiring 25 per cent of water. The shrinkage on drying is 7 per cent, and the tensile strength is over 150 pounds to the square inch, even when rapidly dried. Burning tests resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
05	Salmon	0	28
03	Buff	1	27
01	.....do	2	24
2	.....do	8	14
3	.....do	10	8

The clay is hard after burning to cone 02 (2,030° F.) and reaches viscosity about cone 4 (2,210° F.).

The combined capacity of the plants operating at Brickton is about 15,000,000 brick in a season. The average brick produced were found by the experimental engineering department of the University of Minnesota to have a crushing strength of 2,000 pounds to the square inch.

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 rest of Mille Lacs County is covered with gravelly red drift. Only one attempt has been made to manufacture brick from it—at Wahkon, on the Minneapolis, St. Paul & Sault Ste. Marie Railway. Here the drift contains fully the average amount of sand and gravel and was used with no attempt at cleaning or even at fine crushing. The product made in the one kiln that was burned was naturally of rather low quality. The clay, after being crushed to pass a 40-mesh sieve, has a fairly high plasticity, requiring 20 per cent of water for molding. The air shrinkage is about 5 per cent and the tensile strength about 100 pounds to the square inch. Burning tests gave the following results:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
05	Red	1	14
03	do	3	10
1	do	6	4
2	do	6	5
3	do		

The clay becomes hard at cone 04 (1,958° F.) and reaches viscosity at cone 3 (2,174° F.). Such clay, or even better red drift, may very likely be discovered nearer to favorable markets or shipping facilities. There is probably some near Milaca, but it is not well explored.

In the midst of large areas of red drift there are numerous swamps, some of which cover 40 acres, and in the few places where the clay is exposed in the bottoms of the swamps it is of varying thickness, dependent on the depth of water in the original lake. A few feet of gray and brown clays have been exposed in several places by drainage ditches. A sample taken west of Wahkon, near the middle of sec. 24, T. 42 N., R. 26 W., slakes at once and shows high plasticity, requiring 20 per cent of water for molding. Its tensile strength is about 100 pounds to the square inch, even when rapidly dried, and its air shrinkage is 5 per cent. Burning tests resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
05	Red	0	15
04	do	1	14
02	do	4	9
1	do	6	1

The clay becomes hard at cone 05 (1,922° F.) and reaches viscosity at cone 1 (2,102° F.). It is evidently typical of the lake and swamp clays of the red-drift region. Most of them would be capable of making a thoroughly hard, satisfactory brick.

MORRISON COUNTY.

Clay-bearing formations	Pleistocene: Gray laminated clay. Gray drift. Red drift. Cretaceous: Shale and conglomerate. Huronian: Residual clay.

Red drift has been deposited over most of Morrison County, though in some places the abundance of limestone pebbles makes it more like the northwestern gray type. Gray laminated clays were brought in by streams from the gray-drift area and are the clays now used. Cretaceous deposits are of interest but are not yet developed.

Two or three miles west of Little Falls, Pike Creek has eroded a channel through a deposit of laminated clay which has been utilized for cream-colored brick at two yards. The upper 6 feet is yellow and is underlain by an unknown depth of a much more plastic gray clay, here called joint clay. Thin layers of the joint clay alternate with the yellow in the lower part of the bank now worked, and about 2 feet of the thoroughly fresh joint clay can be mixed with the 6 feet of yellow clay without causing too much danger from checking. The average clay slakes in three 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 to the square inch, even when rapidly dried. As burned at the Minnesota School of Mines experiment station it gave the following results:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
01	Cream	1	30
2	Yellow	2½	25
3	do	3	25
5	do		

The clay becomes too hard to be scratched with a knife at cone 01 (2,066° F.) and reaches viscosity at cone 4 (2,210° F.). It has been used for nearly 30 years, mostly for soft-mud cream-colored brick, though stiff-mud machinery has been used in recent years. Each plant has a capacity of about 40,000 brick a day.

Two River has cut a channel at Bowlus into a deposit of laminated clay which is many acres in extent and appears to be almost identical with that at Little Falls. The tensile strength of this clay, however, is somewhat lowered by rapid drying, and the temperature of vitrification is slightly lower. The Bowlus Brick & Tile Co. was organized several years ago to work this deposit and can manufacture 40,000 soft-mud brick a day.

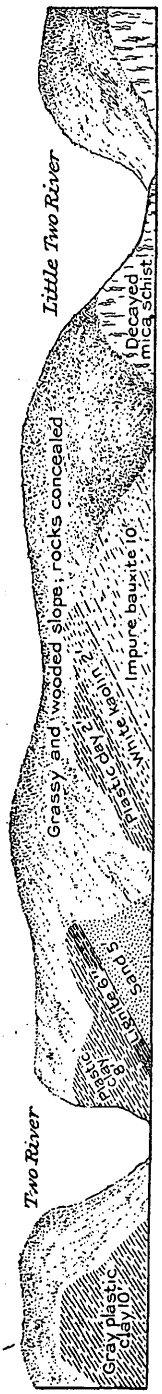


FIGURE 29.—Geologic section along the west bank of Mississippi River near the mouth of Two River. Vertical scale greatly exaggerated.

Along Mississippi River, from Little Falls southward, there are extensive outcrops of the staurolitic biotite schist and its decomposition products that are of interest in this connection. (See fig. 29.) As noted by Winchell,[1] a dike of basic dolerite about 10 feet wide crosses the schists diagonally just below Little Falls. Preglacial decomposition of the slates (or schists) produced a clay which has locally been protected by a more resistant dike from both water and ice erosion. A few miles south of Little Falls, at the Minneapolis, St. Paul & Sault Ste. Marie Railway bridge, there is to be seen a similar layer of decomposed mica schist which apparently had no harder rock to protect it. The decomposition therefore seems to have been general, and the resulting clay is of wide extent under the drift. It could be followed 100 yards and was seen on both sides of the river. With an auger it was shown to be over 6 feet thick and to become 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 is so much decomposed that it is waxy and plastic and can be easily molded. It is interesting to note that in some places the schist is staurolitic, and that the staurolite remains as loose crystals in the clay. Still farther south, near the mouth of Little Two River, material of the same sort is exposed at the wagon-road bridge. This material, on account of the silvery mica scales, formerly caused great agitation and considerable prospecting for silver. The further extent of material of this sort is indicated in a report by Upham.[2] At the mouth of Two River a well was dug 25 feet and bored 4 feet farther into decomposed schist. All the rock thrown out weathered to powder within a few weeks. As a clay, this material 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 (2,282° F.) and is past viscosity at cone 12 (2,498° F.). It can hardly be considered safe for vitrification but is a peculiar type that is more refractory than the common drift and recent clays. An analysis by A. W. Gauger resulted as follows:

[1] Winchell, N. H., Minnesota Geol. and Nat. Hist. Survey Final Rept., vol. 2, p. 596, 1888.
[2] Upham, Warren, idem, p. 599.

Analysis of clay from decomposed biotite schist on Two River.

Silica	57.20
Alumina	18.23
Iron oxides	11.04
Magnesia	1.02
Lime	.72
Soda	.61
Potash	.98
Loss on ignition	5.96
Moisture	2.48
Titanium oxide	1.52
	99.76

Cretaceous clay and shale apparently overlie the clays just described. They dip slightly to the south and are best exposed in the banks of Mississippi and Two rivers, 2 miles east of Bowlus. An instructive outcrop occurs at the bridge on the road from Bowlus to Royalton. (See fig. 29.) A few hundred yards north of the outcrop, near the mouth of Little Two River, where one might expect the same clay to occur higher in the bank, it has evidently been eroded and the Huronian residual material is exposed. The Cretaceous clays were obviously derived by erosion of the weathered Huronian below. In the outcrop near the bridge the material ranges 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 develop much plasticity even after grinding. They remain soft up to a temperature of cone 13, although the more ferruginous sample becomes harder than the other. They stand the temperature of cone 13 (2,534° F.) without the slightest deformation and are evidently somewhat refractory. Analysis No. 1,[1] in the following table, was apparently made on the hard light-gray clay of concretionary type, and both the analysis and the texture indicate the mineral bauxite. The presence of bauxite in the more ferruginous material has been confirmed by Oliver Bowles.

Analyses of bauxitic clay near Little Two River.

	1	2
Silica	19.81	22.42
Alumina	52.43	35.48
Iron oxides	1.32	21.38
Magnesia	....	.43
Soda	.44	....
Lime	....	.59
Ignition	23.23	18.45
Calcium carbonate	1.64	....
	98.87	98.75

1, Analysis by Prof. Dodge; 2, analysis by Oliver Bowles.

[1] Winchell, N. H., Minnesota Geol. and Nat. Hist. Survey Final Rept., vol. 2, p. 602, 1888.

Mr. Bowles further tested the material to ascertain the amount extracted with sulphuric acid and gives the following estimate of the mineral composition:

Mineral composition of bauxitic clay near Little Two River.

Bauxite	22.24
Kaolin	48.21
Limonite	24.98

The bauxite could not be concentrated by simple crushing or grinding and screening. This deposit has probably as high a proportion of bauxite as any other in Minnesota. (See also Redwood County, pp. 216–220.)

A little farther south a shale containing Cretaceous fossils and a thin layer of lignite was sampled near the road bridge over Mississippi River, a few rods up Two River from its mouth. It is exposed for a thickness of 10 feet and can be traced for more than 200 yards along the banks. It is gray and waxy and apparently contains numerous small mica scales. Where exposed it had very little overburden, but if followed any distance it would undoubtedly be found covered with glacial drift. It dips a few degrees toward the south and is underlain by the white basal Cretaceous clay already described. The clay slakes in two 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 (2,210° F.) it is salmon-colored and has just become hard. It reaches viscosity at about cone 10 (2,426° F.). It is hoped that some of the more plastic layers will serve as a plastic bond for the nonplastic refractory clay which occurs in the vicinity.

MOWER COUNTY.

Clay-bearing formations	Pleistocene: Loess. Gray drift. Cretaceous: Shale. Devonian: Shaly limestone.

At Austin clays that appear to be Cretaceous overlie the eroded edges of the Devonian rocks. A quarter of a mile northwest of the Chicago, Milwaukee & St. Paul Railway station the Austin Brick & Tile Co. has opened a deposit 1 to 20 feet thick that underlies perhaps 93 acres. Although the clay is described as Cretaceous, it is somewhat modified and is disturbed apparently by glacial action, and its Cretaceous age is questioned by Sardeson.[1] The clay is variegated in color and 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

[1] Sardeson, F. W., The so-called Cretaceous deposits in southern Minnesota: Jour. Geology, vol. 6, p. 679, 1898.

sandstone and dolomite with a thin upper layer of blue clay rarely over 6 inches thick. (See fig. 30.) The clay slakes in three 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

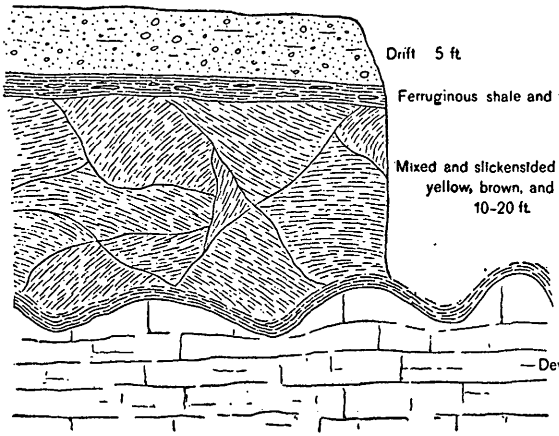


FIGURE 30.—Geologic section at Austin.

of about 100 pounds to the square inch, even when rapidly dried. As burned at the Bureau of Standards it gave the following results:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
013	Salmon	High	25
010	do	do	20
08	do	do	9
06	Red	do	1
03	do	do	1

There was a little trouble from checking, but it was not serious. The porosity was low over a good range of temperature. The clay is hard but not melted at all the specified temperatures.

The factory has a capacity of 60,000 brick a day. Experiments with the different materials available for making high-grade products have yielded excellent results. The clay commonly burns red, but when mixed with the underlying Devonian rock it yields buff and cream-colored ware of equally high grade. The Devonian rock alone burns to a lime rather than to a clay product. To obtain the light colors, a fairly high proportion of the rock must be used. The lime may lower the melting point so much that the mixture is undesirable for making vitrified brick, but it is good for common brick. The 6-inch layer of blue clay between the bedrock and the Cretaceous has also been burned, but the deposit is too small to be of much value. It does not differ greatly from the main body of the clay. Both contain a little organic matter and need thorough oxidation in burning.

At the northwest corner of the property, about a quarter of a mile from the present pit, an excellent clay that is at least 20 feet thick and covers several acres has been developed by drilling. It is somewhat stratified and very highly plastic, though it contains some fine grit. Only 2 or 3 feet of soil lies above it, and no impurities were discovered except a 6-inch layer of sand. The clay slakes in five minutes and is highly plastic but requires only 15 per cent of water for molding. It has a tensile strength of over 100 pounds to the square inch, and its air shrinkage is less than 4 per cent. As burned by the Minnesota School of Mines experiment station, it gave the following results:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
05	Buff	0.3	10
1	do	1.0	9
3	do	1.0	9
5	do	2.0	8
13	Gray		4

The clay becomes too hard to be scratched with a knife at cone 05 (1,922° F.) and is undeformed and perfect at cone 13 (2,534° 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 seems to be Cretaceous.

A clay from the vicinity of Brownsdale was analyzed by C. F. Sidener.[1] Its origin is not stated, but it is probably similar to that near Austin.

Analysis of clay from the vicinity of Brownsdale.

Silica	63.64
Alumina	24.95
Iron oxides	4.90
Magnesia	.20
Lime	1.02
Soda	.66
Potash	.31
Loss on ignition	4.32
	100.00

The gray drift covers nearly all of Mower County, except the bottoms of the stream valleys. At many places, where free from gravel and other coarse impurities, it may be utilized for common red brick.

[1] Minnesota Geol. and Nat. Hist. Survey Nineteenth Ann. Rept., p. 122, 1891.

The loess of this county is unimportant. Abandoned brickyards were noted near Frankford, High Forest, and Leroy, where common brick were made from the glacial drift and the loess.

Limy shale and shaly limestone of Devonian age occur at several localities in Mower County, notably near Frankford along Deer Creek, and near Leroy along upper Iowa River, in the eastern part of the county. The Devonian clays at Austin contain 15 per cent of magnesia and 20 per cent of lime. Probably none are of value for brick or other clay products, for they are all nonplastic, sandy, and impure.

MURRAY COUNTY.

Murray County has only gray drift of the usual pebbly type, which has been tested and found identical in behavior to that used at Hutchinson.

NICOLLET COUNTY.

Clay-bearing formations: Recent: Alluvium. Pleistocene: Gray drift. Cretaceous: Shale.

In Nicollet County, opposite Mankato, brick are manufactured from river 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 2,000,000 brick a season. Similar clay is found at Judson, several miles up the river on the Nicollet County side.

At St. Peter, where the Chicago & Northwestern Railway crosses Minnesota River, a considerable area is occupied by alluvial clay, which has the usual appearance and is apparently of the same quality as that found all along the river. 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 has low plasticity. Its tensile strength is 150 pounds to the square inch and its shrinkage 4 per cent. In burning it gave the following results:

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

The clay becomes hard at cone 01 (2,066° F.) and reaches viscosity at cone 4 (2,210° F.).

Several outcrops of Cretaceous shale are shown on geologic maps of the county. These are very close to New Ulm and are apparently similar to those in Brown County. A shale 10 feet thick in sec. 34, T. 110 N., R. 30 W., that outcrops at John Heinmann's limekiln, can be traced by poorer exposures for several hundred yards along a small creek and by scattered outcrops for miles. The shale, which is easily accessible at the limekiln, underlies glacial drift and contains some small layers of limestone. Its color is variegated, and its quality seems to differ within short distances. (See fig. 31.) 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 to the square inch, though somewhat less if rapidly dried. As burned by the Minnesota School of Mines experiment station it gave the following results:

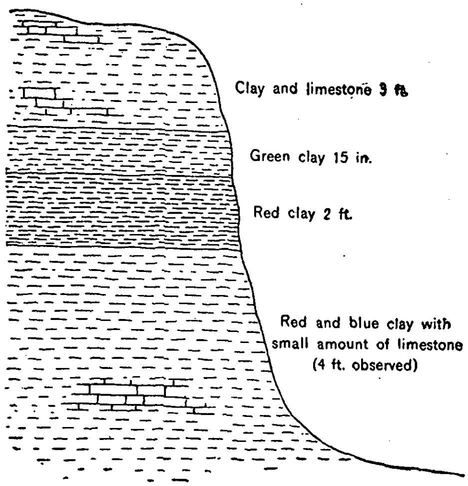


FIGURE 31.—Geologic section opposite New Ulm.

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
05	Salmon	0	14
03	....do	1	13
2	Red	3	9

The clay becomes hard at cone 05 (1,922° F.) and is still undeformed at cone 3 (2,174° F.) if not heated too rapidly. Organic matter is likely to cause the formation of black cores with great swelling and deformation, unless time is allowed for thorough oxidation. Similar clays can be traced by scattered outcrops for several miles along the Nicollet County side of the river.

NOBLES COUNTY.

The clay in Nobles County is the common gray drift, most of which is somewhat pebbly and not very satisfactory, though brick and tile were made at Worthington from a bank less pebbly than the average. If market conditions favored it a plant of the type working at Hutchinson or Jackson might succeed.

NORMAN COUNTY.

Half a mile from Ada is a deposit of the laminated clay of the Red River valley that has been proved over 5 acres and apparently covers the whole region. Borings 15 feet deep did not reach its bottom. There is no overburden but the soil. The clay is weathered yellow for about 10 feet below the surface and includes one 6-inch sandy layer. Brick made from this clay have been used in nearly all the brick buildings in Ada and have stood the test of service very well. The plant has not been operated since 1906. The usual differences are observed between the blue and yellow clays. The blue clay is exceptionally plastic and requires 52 per cent of water for molding. It shows a shrinkage of 17 per cent on drying. It is almost impossible to prevent serious cracking during drying, but if care is used the tensile strength is over 250 pounds to the square inch. This clay has the further defect of containing so much organic matter as to form black cores and to swell considerably, even if heated with great care. The yellow upper part of the deposit apparently gives best results without addition of much of the lower blue clay. A burning test on the yellow clay resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
04	Salmon	1	19
02	Buff	2	16
2	.....do	4	11
3	.....do	6	6
5	.....do	....	....

The clay is hard after burning to cone 03 (1,994° F.) and reaches viscosity at cone 4 (2,210° F.).

The blue clay below this yellow clay, though so fine grained and so full of organic matter that it is difficult to burn, becomes hard at cone 012 (1,634° F.), a much lower temperature.

OLMSTED COUNTY.

Clay-bearing formations:
- Recent:
  - Marsh and lake clays.
  - Alluvium.
- Pleistocene:
  - Loess.
  - Gray drift.
- Ordovician:
  - Shale in Galena limestone.
  - Decorah shale.

Red brick have been made from the glacial and recent clays at a number of localities in Olmsted County. There is hardly a town of any size in the county that has not a deposit of gray drift, loess, or alluvium from which common brick of fair quality could be made. Such brick have been made in years past at Byron, Simpson, Oronoco, Eyota, and Pleasant Grove. The most valuable clay formation in the county, the Decorah shale, has never been utilized, though it should receive attention rather than the inferior glacial drift and alluvium, which in many places are mixed with loess.

The distribution of the Decorah shale in Olmsted County is shown on the accompanying map (fig. 32). Its elevation above sea level is 1,125 to 1,200 feet. The most favorable localities for its use in the manufacture of ceramic products are in the vicinity of Rochester and Byron. In the southern part of the county the shale crops out on

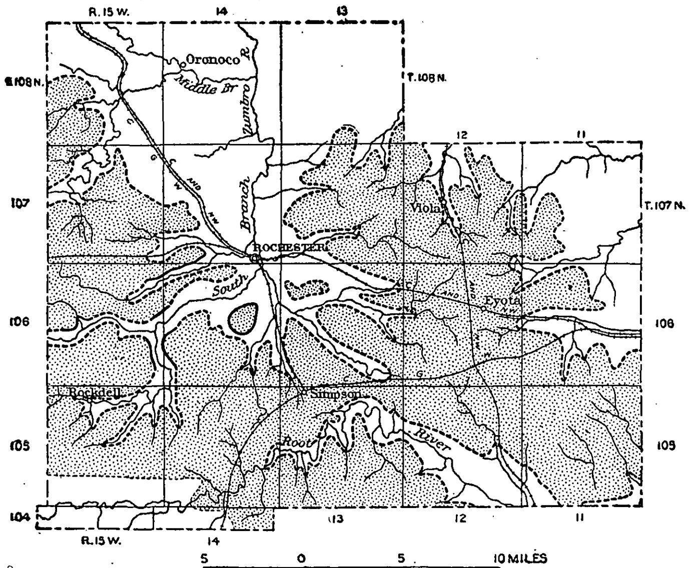


FIGURE 32.—Map of Olmsted County. Dotted area underlain by Decorah shale.

both sides of the north branch of Root River, but it is of small thickness and is inaccessible at present. The relation of the shale to the topography is shown in figure 33. Shale also crops out on the South Branch of Zumbro River. Where the overlying limestones are missing and where the shale is covered by nothing but the glacial drift its presence is not easily detected, but where the neighboring outcrops give no sign of its removal it has been mapped as if present. Around Rochester, where a thin layer of the Decorah shale caps many of the hills, it is covered only by a few feet of drift and soil. Its use is recommended.

About 2½ miles north of Byron, on the Patterson farm, the Decorah is about 50 feet thick and covers many acres. Although the economic conditions are not especially favorable here the shale is certainly indicative of what could be found 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 it has the usual tendency to form a black core and destroy the brick if the heating is too rapid. The brick are red and are hard after heating to cone 012 (1,634° F.) and a temperature of cone 02 (2,030° F.) can be reached in a slow furnace without the loss of the product. The range of vitrification is as great as the Decorah shows elsewhere, and well-vitrified products can be made.

At Rochester there is a considerable deposit of alluvium along Zumbro River, covering an area of 40 acres to a depth of 5 feet or more. Its clay content at least in part is thought to be derived from the neighboring Decorah shale. It occurs in patches alternating with sandy and even gravelly material, as in most alluvial deposits. A sample taken on Charles Kruessel's land slakes in one minute, is

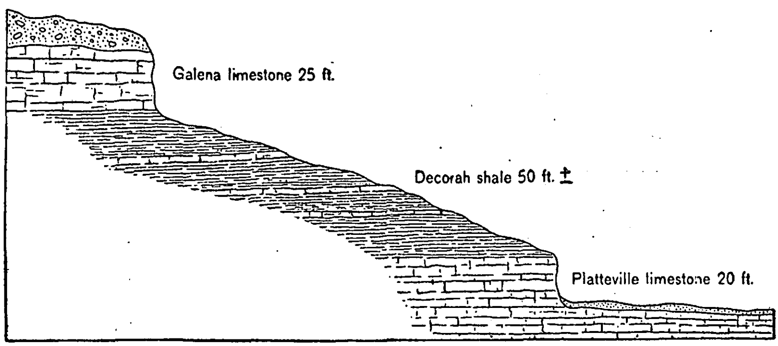


FIGURE 33.—Profile showing topographic features of Decorah shale outcrop in Olmsted County.

highly plastic, requires 32 per cent of water for molding, and shrinks 6 per cent on drying. Burning tests gave the following results:

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

The clay becomes hard at cone 05 (1,922° F.) and has not reached viscosity at cone 5 (2,246° F.). It has thus a range of vitrification of considerably over 300° and should be capable of burning to thorough vitrification without loss. Its extent and quality recommend it for further investigation.

A mile south of Byron, at a bridge on the county road, there is an exposure of 5 or 6 feet of the Galena shale interbedded with limestone. This shale is not of as good quality as the sample from Fillmore County (pp. 158–162). It contains a larger proportion of lime and requires a higher temperature for thorough burning, its plasticity is not so good, 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 (2,210° F.).

For 25 years a plant was at work near Byron station, on the Chicago & Northwestern Railway, on a deposit of yellowish sandy loess, which is 4 feet thick and extends over many acres. Over a million brick a year were produced, but the plant was burned in 1910 and has apparently been abandoned. (See fig. 9, p. 99.)

OTTER TAIL COUNTY.

Clay-bearing formations { Pleistocene:
Gray laminated clay.
Gray drift.

In Otter Tail County the gray drift is abundant, but the widespread laminated clays are much more valuable.

In Fergus Falls a deposit of laminated clay was used 20 years ago in making a rather soft and poor grade of yellow brick. The poor grade was possibly due in part to the method of burning, but probably also to the sandy nature of the clay. The clay is covered by only a thin layer of soil and contains no pebbles. Its working qualities seem to be satisfactory, though its plasticity is low. It shrinks 4 per cent on drying and develops a tensile strength of 100 pounds to the square inch. It burns buff and has an absorption of 35 per cent up to cone 2. Viscosity is reached at cone 5. If market conditions are favorable it is worthy of further investigation. The hills south of Fergus Falls may contain similar clay.

Two miles west of Perham station is a deposit of laminated clay that covers at least 20 acres and is at least 15 feet thick. Yellow and blue-gray clays alternate in this deposit, and the oxidation that produced the yellowish color apparently affected the beds that allowed more rapid circulation. A very few limestone pebbles and a great many cylindrical ferruginous concretions were observed. The clay lies under an overburden of thin soil. Its working qualities are fair, though it is likely to crack in drying. A burning test resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
03	Buff	5	24
01	do	6	20
2	do	7	15
3	do	9	3

The clay is hard after burning to cone 03 (1,994° F.) and reaches viscosity at cone 3 (2,174° F.) but has a strong tendency to warp and check and cause loss. The Northwest Brick Co. has been producing common yellow brick from it for nearly 40 years. Economic conditions, except in the matter of railroad shipping facilities, are excellent.

The Deer Creek Brick Co. has opened a pit 4 miles northwest of Deer Creek, in which are exposed 15 feet of yellow clay and 15 feet of blue-gray clay, all laminated in horizontal layers. The clay underlies 3 to 6 feet of bouldery drift. Its working qualities seem to be excellent. It burns hard and buff-colored at cone 2 and reaches viscosity at cone 6. The company, which was organized several years ago, has been producing about 10,000 brick a day on half-day shifts.

At two points near Battle Lake laminated clays of the same type are known. A. C. Hatch's brickyard used a clay which occurs on the opposite side of Battle Lake, is mined by blasting when frozen, and is hauled across the lake on the ice. A reasonable 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, deposits of similar clay more than 12 feet thick cover many acres.

At Pelican Rapids the following section was observed in sec. 22, T. 136 N., R. 43 W.:

Section of drift at Pelican Rapids.

	Feet.
Gray drift	1–15
Yellow laminated clay	12–14
Blue laminated clay	4– 6
White sand.	

The clay, both yellow and blue, was worked until about 1905, when a part of the deposit was reached in which the overburden was so great that operations were no longer profitable. Each clay slakes promptly and shows a fair degree of plasticity with 30 per cent of water. The top of the yellow clay is in some places more sandy than the clay below. The tensile strength is about 150 pounds to the square inch, and the air shrinkage is 6 per cent. Burning tests were more favorable for the blue clay, which gave the following results:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
03	Cream	1	27
02	.....do	2	26
01	Buff	4	25
2	.....do	9	16
5	.....do		

The clay is hard after burning to cone 02 (2,030° F.) and reaches viscosity at cone 4 (2,210° F.). The yellow clay has a similar but slightly more rapid vitrification.

A mile north of Pelican Rapids is a very extensive accumulation of clay more than 10 feet thick, which has about the average character of the gray drift. It can hardly compete with the laminated clays near by.

PENNINGTON COUNTY.

At Thief River Falls a considerable deposit of clay 4 or 5 feet thick, probably worked over by Lake Agassiz, was used many years ago. The deposit is nearly worked out so far as satisfactory material is concerned. The fact that excellent brick were made here indicates that if other alluvial clays are found they may be profitably developed.

PINE COUNTY.

Clay-bearing formations:
- Recent: Swamp clay.
- Pleistocene:
  - Red laminated clay.
  - Red drift.

The red drift of most of Pine County was deposited by a glacier that traversed the Lake Superior basin, but older red drift from the north lies below, and the gray drift extends into the southern part of the county. Recent swamp clays are most promising and occur at many accessible points. In a few years, if railroads are extended to points along St. Croix River, it may be possible to develop red laminated clay at Sunshine and many places near Grantsburg. These clays are almost identical in occurrence and behavior with the laminated clays now extensively used at Menomonie and Grantsburg, Wis. For analysis of this red clay see page 97.

A plant was in operation for many years just south of Pine City along the railroad, using a deposit of glacial outwash. The clay slakes at once and is too sandy to show much plasticity. It shrinks only 2 per cent on drying and has a tensile strength of over 100 pounds to the square inch. Burning tests resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
04	Red	0	16
02	.....do	0	14
1	.....do	1	11
3	.....do	2	10

The clay is hard after heating to cone 02 (2,030° F.) and reaches viscosity at about cone 4 (2,210° F.).

PIPESTONE COUNTY.

A large territory around and east of Pipestone is covered with gray drift over 10 feet thick. As compared with that at Hutchinson, which is successfully used, this material contains 22 per cent of sand instead of 30 per cent, and 6 per cent of lime instead of 9 per cent, but as the clay vitrifies with about the same range and temperature the slight differences are of no consequence. The shipping facilities at Pipestone are favorable, four railroads branching in different directions. Competition is almost entirely from the south, partly from Sioux City, Iowa, and partly from Luverne, in Rock County, Minn. It seems certain that products of the excellent quality now produced at Hutchinson can be made here, and this locality is recommended for careful consideration. (See fig. 10, p. 100.)

POLK COUNTY.

Clay-bearing formations:
- Recent: Lake clays.
- Pleistocene:
  - Silts of the Red River valley.
  - Gray drift.

The silts of the Red River valley are worked at Fertile, East Grand Forks, and Crookston. They are of several types, because clays accumulated in the Lake Agassiz basin by several different methods. Lake clay has been tried out at Langby. The pebbly drift is not used.

At Fertile the deposit resembles a river delta, occupies about 40 acres to a depth of 40 feet, and is distinctly bedded, the beds dipping toward the present river channel. The clay is yellow and calcareous and has very little overburden. Many sandy layers are included and are in proper proportion to improve the working quality if the whole section from top to bottom of the bank is used. The clay slakes in five minutes and becomes highly plastic. The air shrinkage is 6 per cent, and the tensile strength is about 130 pounds to the square inch. Burning tests resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
03	Buff	0	25
1	do	0	24
3	do	5	18
4	do	10	9
5	do		

The clay is hard after burning to cone 1 (2,102° F.) and reaches viscosity at cone 6 (2,282° F.). The plant is producing cream-colored and white brick by the stiff-mud process. The capacity is about 3,000,000 brick a season, but the brickmaking is interrupted to make some hollow blocks and draintile. The brick have been tested by

E. Brydone-Jack, of Winnipeg, and have a crushing strength of 2,000 to 3,500 pounds to the square inch. The hollow brick have a strength of over 700 pounds to the square inch.

Two companies are operating on laminated clays at Crookston. The Boukind Carlson Brick Co. has a deposit within the city limits which can be traced along the river and is known to a depth of at least 12 feet. It is covered only with soil and is underlain by brown and blue clay of unknown thickness. It contains a few limestone pebbles and limy concretions. The laminae are paper-thin in the upper part of the bank but thicken to 3 or 4 inches in the lower part. The clay can not be rapidly dried without checking, and it shrinks 10 per cent in the process; but it is plastic and has a tensile strength of 160 pounds to the square inch. Burning tests resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
03	Buff	1	24
2	..do	2	20
4	..do	7	8
6	..do		

The clay is hard after burning to cone 2 (2,138° F.) and reaches viscosity at cone 6 (2,282° F.). The plant produces about 4,000,000 common brick a season by a soft-mud process. The fuel has been wood, but recently oil fuel has been tried. The Crookston Brick & Tile Co. exploits the same deposit close to the sawmill. The clay here, as exposed in the pit, is a little more sandy but otherwise is of the same character as that just described. The capacity of the plant is about the same. The city building inspector of Minneapolis, in testing a set of six brick from this deposit at Crookston, found a range from 1,950 to 3,350 pounds to the square inch, with an average of 2,500 pounds. The blue clay of the lower levels shows the usual checks in drying and is so full of organic matter that it is very difficult to prevent black cores. It burns hard, however, at cone 010 (1,742° F.), a very low temperature.

At East Grand Forks the silts are 100 feet deep and extend for miles up and down the Red River valley. The upper 5 feet is leached and weathered yellow, and this portion has been used for a long time in 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 North Dakota side, for an even longer time. The same company controls the yards in both North Dakota and Minnesota. Steam shovels and more modern machinery have been installed on the North Dakota side, so that if the market demand is not at its greatest, the Minnesota plant is closed; but the character of the clay is said to be essentially the same at both plants. The clay slakes at once and has a very low plasticity. It requires 26 per cent of water for molding and shrinks less than 4 per cent on drying. Its tensile strength is well above 100 pounds to the square inch. As burned at the Minnesota School of Mines experiment station it gave the following results:

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

The clay becomes hard at cone 01 (2,066° F.) and reaches viscosity at cone 5 (2,246° F.). It is capable of being burned to hard, porous brick. The plant on the Minnesota side of the river has a capacity of about 50,000 brick a day.

The North Dakota Geological Survey[1] obtained the following results on clay from Grand Forks:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
010	Orange	0.5	31
05	Pink	1.0	33
03	Cream	.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.

Several analyses of this clay from Red River are available, as follows:

Analyses of the leached silts of the Red River valley.

	1	2	3	4
Silica	48.30	51.27	29.45	53.32
Alumina	8.16	9.33	14.04	8.87
Iron oxides	2.84	3.52	4.51	4.71
Magnesia	4.93	2.31	.54	6.62
Lime	16.34	11.15	26.30	9.21
Soda	Undet.	2.08	Trace.	6.60
Potash	Undet.	.50	Trace.	2.26
Loss on ignition	18.00	....	+21.80	6.07
Moisture	....	....	....	1.94
Titanium oxide	....	....	....	.37
	98.57	....	96.64	99.97

1. Analysis furnished by the Red River Valley Brick Corporation.
2. Leonard, A. G., North Dakota Geol. Survey Fourth Bienn. Rept., pp. 184–186, 1906.
3. Dodge, J. A., Minnesota Geol. and Nat. Hist. Survey Ninth Ann. Rept., p. 447, 1881.
4. Clay from yard at East Grand Forks. A. W. Gauger, analyst.

The underlying gray clay on the Minnesota side was more plastic and showed a greater shrinkage than the clay that was being worked.

[1] Leonard, A. G., Economic geology of North Dakota clays: North Dakota Geol. Survey Fourth Bienn. Rept., pp. 184–186, 1906.

A burning test resulted in a brown instead of a buff brick and the temperature of fusion was a few degrees lower.

In the neighborhood of Lengby there are several lakes in which clay deposits overlie common clay drift. There is hardly enough of the lake clay to be used alone, and the gray drift is, as usual, full of pebbles. If the lakes were drained, as seems quite possible, clay deposits of considerable thickness would be exposed, judging from current reports. The good quality of the lake clays for common brick is pretty well determined by some brick that were burned eight years ago for the village school.

POPE COUNTY.

At Glenwood a small plant was at work many years ago on a superficial leached deposit of gray drift, from which most of the limestone had apparently 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 plasticity, shrinkage, and strength are fair, it does not burn hard until within a few degrees of the temperature of fusion. It is therefore unsafe for hard-burned brick. Gray drift of the usual quality is abundant, however, along all the hills in the neighborhood, and, if cleaned, is available for brick and tile.

RAMSEY COUNTY.

Clay-bearing formations	Pleistocene: Red laminated clay. Gray laminated clay. Red and gray drift. Ordovician: Decorah shale.

The Decorah shale, which is used so extensively at West St. Paul, in Dakota County, occurs also in Ramsey County, but only in localities where property is too valuable for excavation. The only Pleistocene materials used recently for brick were also on the Dakota County side.

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

Section of the drift in Ramsey County.

	Feet.
Loam	3–10
Gray drift:	
(*d*) Sand, gravel, and boulders	0–10
(*c*) Laminated brick clay	0–16
(*b*) Sand, gravel, and boulders	20
(*a*) Till (seen)	0– 2
Red drift:	
(*b*) Laminated brick clay	0–10
(*a*) Till	10–20

[1] Winchell, N. H., Minn. Geol. and Nat. Hist. Survey Final Rept., vol. 2, p. 371, 1888.

Leached gray drift has been used in the northern part of the city of St. Paul for red brick, but it has the common defect of containing too much limestone.

The red laminated clay is somewhat sandy, like that at Stillwater. It was once used on Daytons Bluff. Just south of Como Park laminated clays 10 feet thick are visible beneath 5 to 20 feet of gray drift at the crossing of Lexington Avenue under the Northern Pacific Railway. A sample taken here indicates the quality of these clays in the neighborhood of the Twin Cities. In St. Paul, especially between Sibley and Wacouta streets, red laminated clays were once exposed in quantities. In both these places the value of the land is undoubtedly so great that ceramic industries will not make use of the clay, but the samples indicate the quality of material of this type. Tests by the Bureau of Standards show that the clay contains too much fine sand to work well in an auger machine. The water needed for molding is 20 per cent and the shrinkage on drying is 4 per cent. The clay 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 (2,138° F.). Soft-mud brick could be made from such a clay as this, as has been demonstrated successfully at Menomonie, Wis., where two plants make use of clay of this type and have developed the work to such an extent that their brick are shipped across Minnesota and even farther west. Analyses of the laminated red clay, by F. F. Grout, are given below. In the mechanical analysis the small lumps of shale were not easily broken up by shaking, or even rubbing with a rubber pestle, so that the percentage of fine clay reported is probably smaller than it should be.

Analyses of red laminated clay.

Chemical analysis.	
Silica	57.79
Alumina	12.63
Iron oxides	8.88
Magnesia	4.11
Lime	3.33
Soda	1.75
Potash	2.71
Loss on ignition	6.10
Moisture	2.50
Titanium oxide	.82
	100.62

Mechanical analysis.	
Fine clay	28.0
Coarse clay	29.7
Silt	42.0
Fine sand	.3
Coarse sand	Trace.
	100.00

A large part of the county is underlain by red drift of a common pebbly type, though in many places gray drift overlies this deposit. In St. Anthony Park, near the city limits, between Minneapolis and St. Paul, the drift seems to be coarsely and irregularly stratified. It consists of a pebbly clay which slakes in two minutes and shows low plasticity with 21 per cent of water. It shrinks 4 per cent on drying and has a tensile strength of 100 pounds to the square inch. Burning tests resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
06	Salmon	0	18
02	....do	1	14
01	Red brown	3	12
2	Greenish brown	5	4
3	....do	5	4

The clay is hard after heating to cone 02 (2,030° F.) and reaches viscosity at about cone 4 (2,210° F.).

RED LAKE COUNTY.

Half a mile from the station of Red Lake Falls is a deposit of gray drift, modified by Lake Agassiz, which was used for brick-making many years ago, but the enterprise has been abandoned, probably because of the difficulty with the pebbles. If a cleaning process of either the Hutchinson or the Jackson type could be successfully applied a plant might pay, for the situation seems to be favorable both as to market in a part of the State which is being rapidly settled and as to shipping facilities near the Great Northern and Northern Pacific railways.

REDWOOD COUNTY.

Clay-bearing formations:
- Recent: Alluvium.
- Pleistocene: Gray drift.
- Cretaceous:
  - Shale.
  - Basal white clay.
- Archean: Residual clay.

Most of the gray drift of Redwood County is not so good as the alluvium of Minnesota River that is used near Morton for good brick and tile. Thin layers of Cretaceous shale have not proved of value, but the underlying concretionary white clay and the associated Archean residual clay warrant more 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 and the lower 50 feet consists of weathered granite gneiss. (See fig. 34.) This clay in some places underlies the basal Cretaceous clay. The outcrops extend for nearly a mile along the river. The clay is well situated with respect to railroads, but the property at the exact point of the outcrop is a State park, and the scenic features prohibit the development of ceramic industries on the ground. Probably other deposits of the same type lie near by under the drift.

As tested in the laboratory, the clay slakes in one minute. Its plasticity is low, and it requires 33 per cent of water. Its tensile strength is about 50 pounds to the square inch. It burned salmon-colored and steel-hard at once 1 (2,102° F.) and became brown at cone 13 but was still undeformed. It gave every indication of being a refractory clay of good grade. Where the original rock is highly ferruginous the residual clay may not be as white and refractory as the average. At one point in this gorge the red stain of iron oxide

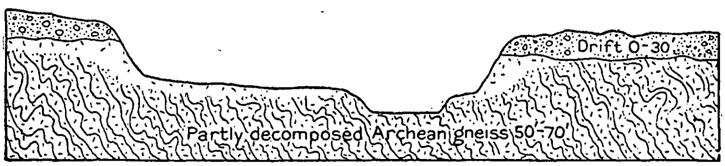


FIGURE 34.—Section across the gorge of Redwood River below Redwood Falls. The bluff for about 50 feet is largely kaolin derived from the weathering of granite gneiss. Under the drift the weathering to kaolin may have been relatively shallow.

is so great that a "red paint mine" was opened, and a few tons of paint rock was shipped.

Between Redwood Falls and Morton, on the south bank of Minnesota River, a test pit has been dug by the Morton Brick & Tile Co. into a bank of residual decomposed gneiss, which has retained its granitoid texture. The ferromagnesian minerals have altered to chlorite and the feldspar to clay. The clay burns gray, becomes hard at cone 2 (2,138° F.), and is thoroughly vitrified, but not melted, at cone 13 (2,534° F.). Analyses by F. F. Grout follow:

Analyses of decomposed gneiss from locality south of Morton.

Chemical analysis.		Mechanical analysis.	
Silica	60.61	Fine clay	5.6
Alumina	18.12	Coarse clay	8.9
Iron oxides	7.51	Silt	25.4
Magnesia	1.14	Fine sand	21.4
Lime	.03	Coarse sand	38.7
Soda	.54		
Potash	3.56		100.0
Loss on ignition	7.20		
Moisture	.28		
Titanium oxide	1.30		
	100.29		

Near Morton, but south of the river, on the road to Redwood Falls, the river bluff shows one of the most instructive outcrops of the Cretaceous beds in Minnesota. (See fig. 35.) The basal Cretaceous is very thick and shows a definite conglomerate at the contact with the Archean and enough of the overlying Cretaceous shale to determine the relations definitely. Both the concretionary or pebbly clay (see Pl. XI, *B*, p. 88) and the smooth white clay, whether free from grit or not, burn white and soft and undeformed at cone 33 (3,254° F.) and are therefore extremely refractory fire clays.

The deposit here is not large enough to make it worth while to attempt the production of vitrified ware by the use of mixed clays with a high percentage of the fire clay, but it is not at all impossible that larger deposits might be found. Outcrops in Renville County are somewhat thicker than here, and a similar stratum may be traced up and down the Redwood gorge wherever the Archean

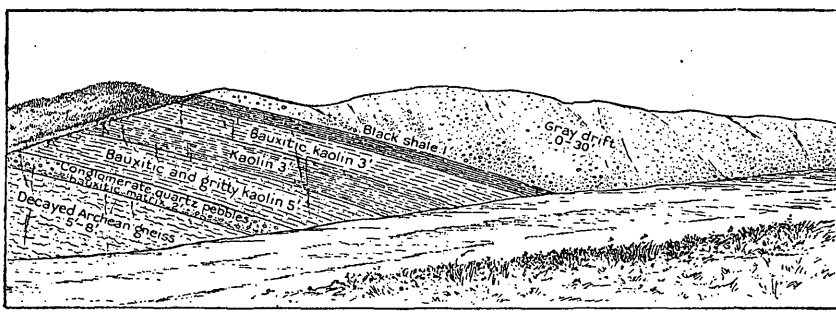


FIGURE 35.—Section on road from Morton to Redwood Falls.

clays form the main part of the bluff. Other exposures are easily found. These scattered outcrops strongly indicate the existence of a large body of high-grade clay. Relatively small amounts of the fire clay unmixed with other clays have been worked up into fire brick, but these, like the fire brick made at New Ulm, lack strength after repeated heating and cooling. Their refractoriness is, however, all that could be desired. Tests of these clays by the Bureau of Standards showed low plasticity even after grinding. For molding 29 per cent of water is required, and the drying shrinkage is 4 per cent. The burned color is not quite so clear a white as that of commercial kaolin. The softening point is above cone 32 (3,218° F.). There is a rather serious tendency to check in burning. It is likely that the burned color of the clay could be made as good as that of commercial kaolins by a washing process. Analyses by the Bureau of Standards are given on page 219. (For other analyses see p. 79.)

Analyses of Cretaceous clays from deposits near Morton.

	Smooth white clay.	Concretionary clay.
Silica	45.14	44.12
Alumina	37.94	38.39
Iron oxides	1.01	1.06
Titanium oxide	1.09	1.17
Lime	.46	.28
Magnesia	.08	.11
Soda	.36	.30
Potash	.09	.17
Loss on ignition	14.10	14.70

In view of the concretionary texture of some of these beds, especially in connection with the concretionary texture of bauxitic beds of Morrison County, a careful test of these clays for bauxite was made by Oliver Bowles. The portion soluble in sulphuric acid indicated only 3 to 4 per cent of bauxite.

The Minneapolis Fire Brick Co., of Minneapolis, has acquired a property near these exposures and by the use of some Missouri clay for a binder makes excellent fire brick. This company finds the Cretaceous white clay over 30 feet thick.

In Redwood County, near Morton, Renville County, the alluvium of Minnesota River occupies a great many acres of the river flat to a depth of 10 feet. The section consists of sod, 5 feet of black sandy clay, and 5 feet of yellow-sandy clay, underlain by 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 to the square inch, though it may be somewhat less if carelessly dried. The air shrinkage is 7 per cent. As burned at the Minnesota School of Mines experiment station, the results are as follows:

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

The clay becomes too hard to be scratched with a knife at cone 05 (1,922° F.) and reaches viscosity a little above cone 2 (2,138° F.). The Morton Brick & Tile Co. for many years manufactured red brick and draintile in a very excellent plant of medium capacity. It uses an auger machine and sometimes a re-press and has six round down-draft kilns. The company has made a series of experiments to ascertain the possibilities of making paving brick or some high-grade product by the addition of small amounts of the high-grade residual and Cretaceous clay of the neighborhood to this alluvium but with little success.

RENVILLE COUNTY.

Clay-bearing formations
- Recent: Lake clays.
- Pleistocene: Gray drift.
- Cretaceous: Clay.
- Archean: Residual clay.

Lake clays of unknown quality are reported at Boon Lake, in the northeast corner of Renville County. The gray drift is of the common type, and the older formations resemble those in Redwood County. Large deposits of Archean residual clay and basal Cretaceous clays occur from Beaver Falls eastward along Minnesota River. On Birch Cooley Creek, three-quarters of a mile up the creek from the river bluffs, the concretionary bauxitic clay reaches a thickness of 18 feet—the maximum recorded in Minnesota. Well records show that it is at many places beneath 100 to 300 feet of drift. This drift overburden is the chief drawback to its extensive development.

On the north bank of Minnesota River, opposite the test pit of the Morton Brick & Tile Co., in Redwood County, several ravines have cut through the drift and into a decomposed granite, exposing a yellowish mass that differs somewhat from the green-mottled clay of Redwood County but that burns with essentially the same qualities. Samples of these clays have been used as refractory material at the plant of the Morton Brick & Tile Co. The depth of such material over other parts of the county back from the river may be indicated by a well record at Seaforth, which shows white clay at depths of 50 to 85 feet. A clay of this type, found by drilling, was analyzed by Prof. L. B. Pease, of the Minnesota School of Mines experiment station, who found that it contained 62.04 per cent of silica, 25.54 per cent of alumina, and 1.24 per cent of iron oxide. This is probably a good average for the material seen. However, a somewhat different composition is shown in the following analysis by A. D. Meeds:[1]

Analysis of decomposed gneiss from Birch Cooley.

Silica	41.71
Alumina	34.61
Ferric oxide	4.58
Ferrous oxide	6.88
Magnesia	.22
Lime	1.16
Soda	.11
Potash	Trace.
Loss on ignition	12.69
	101.96

[1] Hall, C. W., The gneisses and associated rocks of southwestern Minnesota: U. S. Geol. Survey Bull. 157, p. 76, 1899.

About 3 miles west of Fort Creek a bed of grayish-white clay 7 feet thick crops out with level stratification in an excavation on the upper side of the river road, in sec. 34. This deposit may be related to the white concretionary or conglomeratic clays in Redwood County (pp. 216–220) and in Birch Cooley, in Renville County.

Winchell[1] gives the following notes:

At a point 2 miles below the lower Sioux Agency, sec. 10, T. 112, R. 34 [in Birch Cooley], on the north side of the Minnesota, a smaller 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 limy 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 inclosed in the mass. It is rather hard when dry and nearly white. It is associated with a blue clay, the relations of which can not here be made out.

At a point a little farther up this creek appears a heavy deposit of concretionary, 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 one-fourth or one-half inch in diameter; seen 18 feet. Under this is the light concretionary clay or marl already described.

This description evidently refers to a bauxitic clay. The thickness (18 feet) is the greatest reported in the State.

The gray drift was sampled in a few places near Olivia, as it would be desirable to develop brick material there. On several areas of low ground the lime pebbles are less abundant than the average. However, no good-sized body of clay has been found sufficiently free from them to be satisfactory, except by the application of a cleaning process such as that used at Hutchinson. The best samples were found a few rods north of the railroad, half a mile east of the station. These clays slake in five minutes and are highly plastic with 33 per cent of water. They shrink 8 per cent on drying and have a strength of over 300 pounds to the square inch. Burning tests resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
06	Salmon	1	20
04	Red	2	20
02	....do	4	12
1	Red brown	7	4
3	Gray brown	9	2

The clay is hard after burning to cone 03 (1,994° F.) and reaches viscosity at cone 3 (2,174° F.).

[1] Winchell, N. H., Minnesota Geol. and Nat. Hist. Survey Second Ann. Rept., p. 187, 1874; also in Final Rept., vol. 2, p. 197, 1888.

RICE COUNTY.

Clay-bearing formations:
- Recent: Lake and swamp clay.
- Pleistocene:
  - Aftonian (?) soil (no value; see p. 92).
  - Gray drift.
- Ordovician: Decorah shale.

Common red bricks are made from leached gray drift at Faribault. In former years brickyards were operated on gray drift at Northfield, Morristown, and several other localities in Rice County. The Decorah shale crops out for many miles along both sides of Straight River, and also far along 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.

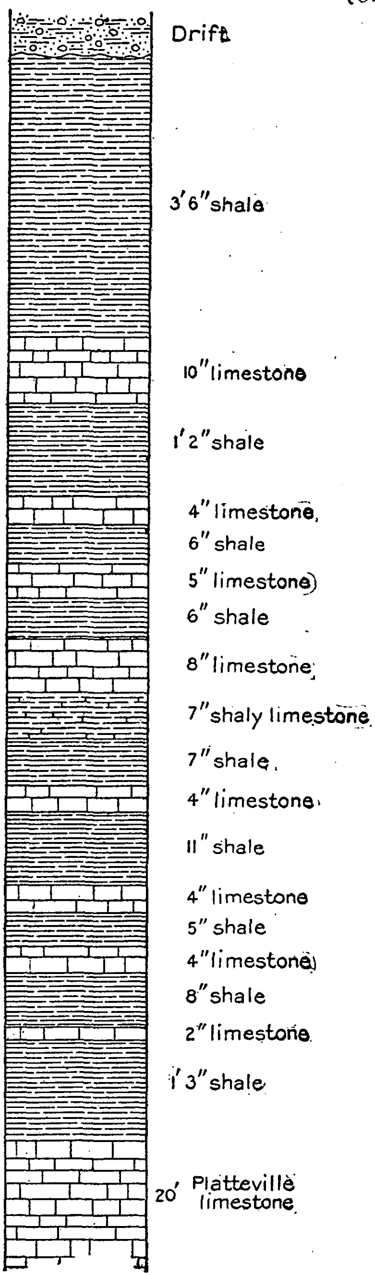


FIGURE 36.—Geologic section of the Decorah shale south of Faribault.

A very promising outcrop of the Decorah shale occurs 1½ miles south of Faribault and a quarter of a mile above the Chicago, Rock Island & Pacific Railway bridge over Straight River. At this point 10 feet of shale, with interbedded limy layers, lies just above the Platteville limestone and underlies (with an intervening thin bed of limestone) several feet more of shale below the drift overburden. (See fig. 36.) The shale as sampled is considerably weathered. This is one of the points where the Decorah shale should be used, the tensile strength of these clays being considerably greater than that of the clays in the same formation farther north. The water required for molding is 31 per cent and the air shrinkage 7 per cent. A burning test on the main shale bed, conducted by the Minnesota School of Mines experiment station, resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
06	Salmon	0	19
04	.....do	1	20
01	Cream	2	23
2	.....do	5	....
5	Buff	10	....

The clay becomes too hard to be scratched with a knife at cone 02 (2,030° F.) and is not yet viscous at cone 6 (2,282° F.). It showed some tendency to develop an efflorescence (kiln white), but this would not persist to vitrification.

The upper shale at this outcrop is more fusible and has a much greater tendency to form black cores and develop bleb structure. A "combustible shale" from this county, probably from the Decorah shale, was analyzed years ago by S. F. Peckham,[1] and found to contain 22.87 per cent of organic or combustible matter. The upper shale near Faribault is probably not so carbonaceous. It burns salmon-colored at moderate temperatures. The clay is hard after being heated to a temperature as low as cone 010 (1,742° F.), and the absorption is small, as is usual with the Decorah shale. Vitrification is gradual, and the heat may be carried to cone 02 (2,030° F.).

There are many extensive swamps in the county, and a sample was taken from one with an area of about 60 acres, 6 miles northwest of Faribault. In this swamp the clay is overlain by about 2 feet of loam and peat. The clay, which seems to be free from sand and gravel, slakes in four minutes and develops a high plasticity with about 30 per cent of water. It shrinks about 8 per cent on drying and cracks so badly that its tensile strength can hardly be measured. If sand were available in the neighborhood and market conditions were favorable, it might be used for common red brick. Burning tests, unless conducted with slow heat and long oxidation, entirely ruin the brick. The following results were obtained:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
04	Red	3	14
02	.....do	3	13
01	.....do	4	12
2	.....do	5	4
4	.....do	6	3

The clay is hard after burning to cone 03 (1,994° F.) and reaches viscosity if slowly burned at about cone 4 (2,210° F.).

ROCK COUNTY.

At Luverne a brick and tile plant has been active at times for the last 20 years, producing excellent brick and tile from the gray drift, which covers a large part of Rock County and is worked here to a

[1] Minnesota Geol. and Nat. Hist. Survey Eighth Ann. Rept., p. 152, 1880.

depth of 10 feet. The limy pebbles that occur in the drift are said to have a less serious effect than usual, and though they may somewhat injure the product the loss by crumbling is very small. The larger pebbles are removed from the clay, and many of the smaller ones are crushed by conical rolls. Four round downdraft kilns are available, and the cooling kilns supply heat for the driers. The plant has a capacity of about 50,000 brick a day. A company making sand-lime brick at Luverne recently bought up the clay-brick and tile plant but did not make a success of either. The tile company plans to resume operations soon. On the south side of the road where the railroad crosses Beaver Creek the gray drift is rather more sandy than the average gray drift and contains much gravel, a large part of which is limestone. (See fig. 10, p. 100.)

ROSEAU COUNTY.

A quarter of a mile from the station at Badger the gray drift has been worked over to some extent by the waters of Lake Agassiz and is rich enough in clay to make brick but contains a rather high proportion of limestone pebbles. The plant is of small capacity and its product is not of high grade.

At Roseau similar modified drift, at least 10 feet thick, covers several acres. It is highly calcareous but contains no limestone pebbles. In working and burning it shows very much better quality than that at Badger. It is hard after burning to cone 2 (2,138° F.) and has an absorption of 32 per cent. A few yellow brick were made from it several years ago.

The recent growth of the town of Roosevelt has led to a search for brick clay in that neighborhood. Two samples sent in—one by Mr. Richard Olson and one by Mr. H. Robberstad, showed high plasticity and strength, with about 7 per cent shrinkage on drying. Mr. Olson's sample gave the following results:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
03	Buff	0	29
2	....do	3	23
4	....do	4	19

The clay becomes hard below cone 2, but even at cone 4 the lime pebbles cause the disruption of the brick.

Mr. Robberstad's sample gave the following results:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
010	Salmon	0	19
06	....do	0	19
03	Red	1	16
2	....do	6	3

The clay is hard at cone 06 (1,886° F.) and reaches viscosity at about cone 3 (2,174° F.). Vitrification is abrupt and should not be attempted, but if the limestone pebbles are no more abundant than appears from the sample good common brick might be made from this clay.

ST. LOUIS COUNTY.

Clay-bearing formations	Recent: Swamp and lake beds. Pleistocene: Gray laminated clay. Red clay of Lake Duluth. Red laminated clay. Red drift. Gray drift. Algonkian (?): Red clastic series. Huronian: Paint rock and slate.

The swamp clays and the red clay of Lake Duluth have been used in a small way in St. Louis County, but other clays occur and may prove to be of value. The red and gray drift do not seem to be of value for clay products. A few houses in West Duluth are built of brick made many years ago from the sticky red clay so common in the neighborhood. At New Duluth, near the steel plant, such clay is covered with a sandy bed, and the combination will make good common brick.

Swamps are numerous in this county, and many of them have deposits of smooth plastic clay. Just south of Tower is a swamp which covers several hundred acres and in which borings have shown 40 feet of clay near the center. The clay is overlain by several feet of peat and contains very few limy pebbles. The North American mine, close to this deposit, is likely to drain off most of the water in the swamp but has not yet done so. The clay slakes at once, shows a high plasticity, and requires 39 per cent of water for molding. The air shrinkage is 13 per cent. The clay can hardly be prevented from cracking, and its tensile strength is consequently small. Burning tests resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
010	Salmon	0	18
06	do	0	20
04	Red	2	11
02	do	6	2

The burning must be conducted slowly to avoid cracking. The clay is hard after heating to cone 010 (1,742° F.) and gradually becomes viscous at about cone 01 (2,066° F.), thus having a fair range but not such as would be required for making sewer pipe or stoneware.

An analysis by F. F. Grout is probably typical of St. Louis County swamp clays.

Analysis of swamp clay from Tower.

Silica	52.92
Alumina	15.05
Iron oxides	6.66
Magnesia	3.78
Lime	5.95
Soda	.97
Potash	2.32
Loss on ignition	8.85
Moisture	3.33
Titanium oxide	.52
	100.35

A plant was started to manufacure brick and tile from this material, but it experienced difficulty in drying the ware. On account of the good range of vitrification, this clay might be valuable for the manufacture of sewer pipe, if it could be safely dried and if the burned ware was strong. However, the low temperature of fusion, as compared with that of most good sewer-pipe clay, indicates a comparatively weak product. If less plastic material could be found in the neighborhood and mixed with this clay its properties might be more satisfactory.

Another swamp clay was sampled at Buhl, where the Grant open-pit mine has removed, in stripping, an extensive body of swamp clay 10 feet thick, together with the underlying gray drift. As this material must be moved anyhow, it might be possible with a little care to separate the clay from the drift. It could be burned to common brick, though it has much the same quality and defects as that at Tower. It is hard after burning to cone 05 (1,922° F.) and viscous at cone 2 (2,138° F.). Enough organic matter is present to require considerable time in burning to avoid black cores.

The gray laminated clays vary slightly in character in different parts of the county. They crop out extensively enough along Littlefork River near Koochiching County to be of some interest. The type has already been described under Itasca and Koochiching counties (pp. 175–178, 182–186). In St. Louis County the deposits are closer to the railroad but are still too far away for economical shipping.

The most accessible of the laminated clays on Littlefork River is on the farm of Gilbert Haugan, 3 miles from Cook, where an extensive deposit is covered only by thin soil. It is somewhat weathered and contains small limy concretions, but no limestone pebbles. The clay slakes in ten minutes and is of medium plasticity, requiring over 40 per cent of water for molding. The air shrinkage is about 15 per cent and the tensile strength 200 pounds to the square inch. Burning tests resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
010	Salmon	2	18
06	do	3	17
03	Red	6	14
01	do		

The clay is hard after burning to cone 010 (1,742° F.) and reaches viscosity gradually at about cone 02 (2,030° F.). The red color of the brick and the tendency to develop black cores indicate that the sample was weathered and contained organic matter and was not entirely representative of the gray laminated type.

A series of samples taken along the river to the county line all resulted in red brick, with only slight variations in physical properties. An instructive outcrop occurs near Ableman's, on the county line at Wigwam Rapids, where the river has removed the laminated clay from the underlying greenstone bedrock surface and exposed the glacial striae. The clay there contains concretions of a type not observed at many other points (see Pl. II, *D*, p. 36), but these would not cause much trouble. The clay slakes in three minutes and is highly plastic with 36 per cent of water. It shrinks 10 per cent on drying and has a tensile strength of 175 pounds to the square inch. Burning tests resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
06	Salmon	3	18
04	Red	5	12
02	do	11	2
1	do	11	1
2	do	12	0

The clay is hard after heating to cone 05 (1,922° F.) and reaches viscosity at cone 2 (2,138° F.). Fragments of Indian pottery have been found in great abundance across the river and in the neighborhood, and may still be found in the garden back of Mr. Ableman's house.

Two samples of clay, probably similar to that described above, sent by Mr. F. D. Lapping, of International Falls, to the Minnesota School of Mines experiment station from sec. 8, T. 70 N., R. 21 W., were partly analyzed, with the following results:

Analyses of clays from sec. 8, T. 70 N., R. 21 W.

	Gray clay.	Red clay.
Silica	54.43	49.60
Alumina	18.15	15.82
Iron oxides	4.20	
Lime	3.98	1.70

At Floodwood the gray laminated clays on the west give place to the red laminated clays on the east. About a mile northwest of the town a well on the land of Mr. McCormick passed through 12 feet of yellow clay and 6 feet of gray clay without finding its bottom. The deposit can be traced over several acres and may extend much farther. It is covered only by a thin soil. The clay slakes at once and has a rather low plasticity, requiring 24 per cent of water for molding. Its tensile strength is well above 100 pounds to the square inch, and it shrinks 2½ per cent in drying. Burning tests of the yellow clay by the Minnesota School of Mines experiment station resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
05	Buff	1	35
1	.....do	4	30
3	.....do	8	21
5	.....do	10	13

The clay becomes hard at about cone 1 (2,102° F.) and reaches viscosity at cone 5 (2,246° F.).

A similar test on the blue clay showed a slightly greater tendency to shrink and warp during the process. It can be burned to hard but somewhat porous buff brick. Other clays of the same neighborhood, described below, yield very different products.

In Floodwood the red laminated clays were discovered in digging a sewer and are exposed along Savanaugh River near its mouth, at the southeast edge of the town. The exposure is 10 feet thick, and the bottom is not seen. Laminated clay of the same type, with a slightly darker, purplish-red color but showing the same behavior in firing, was found in several excavations about 2 miles east of Floodwood. The clay slakes in two minutes, shows 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 to the square inch, and its air shrinkage 6 per cent. As burned by the Minnesota School of Mines experiment station, it gave the following results:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
05	Salmon	1	20
04	Red	3	15
01	.....do	8	6
1	.....do	11	2

The clay becomes too hard to be scratched with a knife at cone 05 and reaches viscosity at cone 1. Clays of several other types were easily accessible, and a number of mixtures were burned, but none seem to show a greater range of viscosity or other especially desirable properties. At lower porosities this clay shows a well-vitrified structure. It resembles very closely the clays developed so successfully at Menomonie, Wis., and it almost certainly will make brick of the same grade as those now shipped in large quantities from Wisconsin into and across the State.

On the railroad above Fond du Lac is an outcrop of soft fine-grained red shale associated with the red sandstone of the west end of Lake Superior. The shale includes a few small gray circular areas, which, except in color, do not appear to differ from the rest of the rock. A chemical analysis of this rock gave the following result:[1]

Analysis of shale from Fond du Lac.

Silica	48.92
Alumina	18.45
Ferric oxide	16.88
Ferrous oxide	.57
Lime	.70
Magnesia	3.68
Soda	.48
Potash	1.32
Water	7.14
	98.14

The clay does not slake and is nonplastic. When crushed it can be molded, and burning tests at temperatures between cone 02 and cone 5 yielded an excellent vitrified but somewhat rough red brick. If the clay occurred in larger quantities it would be worthy of further exploration.

On the Mesabi range, notably at Coleraine and Hibbing, the open-pit mines have found, interbedded with the iron ore, bodies of clay that contain iron, though not enough to constitute ore. The clay is highly colored and is commonly known as "paint rock." The layer is variable in thickness, in relation to the associated ore, and in texture. In places the clay is sandy but more generally is smooth and plastic. Where the ore occurs both above and below the paint rock it becomes necessary to remove the paint rock, and if a use could be found for this material it could easily be separated with a steam shovel. 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 to the square inch, and its air shrinkage is 4.5 per cent. In spite of its high content of iron it does not burn hard below

[1] Geology of Minnesota: Minnesota Geol. and Nat. Hist. Survey Final Rept., vol. 5, p. 555, 1900.

2,200° F. but is viscous at 2,500° F. Another material of a claylike sort from the iron formation has been analyzed by C. F. Sidener,[1] with the following results:

Analysis of banded "silica kaolin" from sec. 6, T. 58 N., R. 17 W.

Silica	77.89
Alumina	13.55
Iron oxide	1.83
Magnesia	.36
Lime	Trace.
Soda	.58
Potash	.84
Water	4.45
	99.50

Immediately above the iron ore lies the Virginia slate. The chief outcrops are at the east end of the Mesabi range for a few miles. The slate is highly ferruginous and could hardly be expected to become plastic. It has a very low tensile strength and does not burn hard at a temperature of 2,300° F.

SCOTT COUNTY.

Clay-bearing formations:
- Recent: Alluvium.
- Pleistocene:
  - Gray laminated clay.
  - Gray drift.
- Cretaceous: Clay.

Alluvium occurs along the entire length of Minnesota River in Scott County, and gray laminated glacial clays appear in the bluffs at many points. A sample of gray drift from a deposit 3 miles south of Shakopee has too many limestone pebbles to be of value. At La Huiller Mound, between Jordan and Shakopee, a white clay resembling the Cretaceous farther southwest was sampled by N. H. Winchell.

At Shakopee the river alluvium is known to extend over 20 acres to the unusual depth of 30 feet. A dark clay some distance from the river is more plastic than that closer by, and the two are mixed to produce material proper for soft-mud red bricks. Some repressed brick are made at the same plant. The clay slakes in three minutes and has a rather low plasticity. It requires 23 per cent of water for molding and shrinks 4 per cent on drying. Its tensile strength is about 150 pounds to the square inch and is not much reduced if the clay is rapidly dried. Burning tests resulted as follows:

[1] Minnesota Geol. and Nat. Hist. Survey. Bull. 10, p. 81, 1894.

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
02	Salmon	0	22
2	Brown	3	15
3	.....do	5	13
5	.....do		

The clay becomes hard at cone 01 (2,066° F.) and reaches viscosity at cone 4 (2,210° F.) The plant has a capacity of about 3,000,000 brick a season. Burning is conducted in a patent 30-arch kiln by what is known as the John G. Boss system.

At Blakeley a deposit used in the manufacture of cream-colored brick consists of laminated clay about 30 feet thick, whose upper half shows the characteristic weathered yellow color. The extent of the deposit is somewhat obscured by 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. The tensile strength of both is high—about 150 pounds to the square inch. The upper clay shows an air shrinkage of 1.5 per

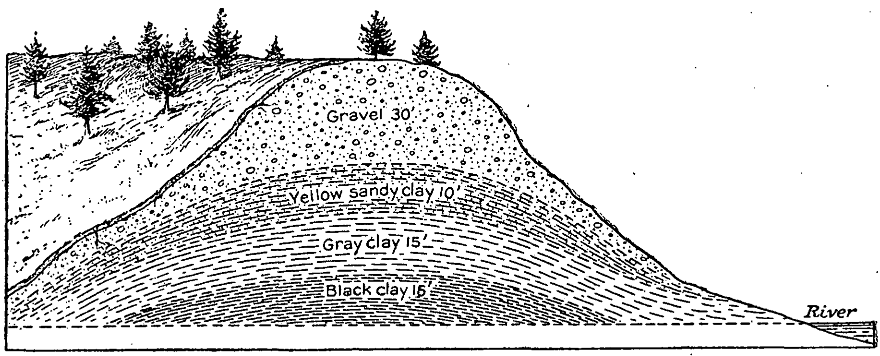


FIGURE 37.—Geologic section south of Belle Plaine.

cent, but the lower shows over 5 per cent. A sample of a mixture such as is used at the plant gave the following results:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
1	Buff	1	30
3	.....do	5	20
4	.....do	7	2

The clay becomes hard at about cone 1 (2,102° F.) and is near viscosity at cone 4 (2,210° F.). A plant at Blakeley has been operated pretty steadily since about 1890, at first on common brick but recently in large part on hollow ware, produced with a stiff-mud machine that has a capacity of about 35,000 a day.

A plant was operated about a mile south of Belle Plaine on a bank whose structure is shown in figure 37. The different parts of the bank are not regular in their stratification, but the bedded clay exposed forms a sort of arch about 100 yards across. Each part of the section grades into the overlying and underlying parts. The yellow silt can be used as sand in tempering the lower clay. The clay slakes at once, requires only 21 per cent of water for molding, and is never very plastic. Soft-mud brick are to be made from it. The shrinkage on drying is 2 per cent, and the tensile strength less than 100 pounds to the square inch. Burning tests resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
02	Cream	0	35
01	Buff	0	33
1	.....do	1	33
4	.....do	2	28
6	.....do	3	....

The clay is hard after burning to cone 01 (2,066° F.) and reaches viscosity at cone 6 (2,282° F.). The plant can produce about 30,000 soft-mud cream-colored brick a day.

SHERBURNE COUNTY.

Clay-bearing formations:
- Pleistocene:
  - Gray laminated clays.
  - Red drift.
  - Gray drift.

In several areas near the town of Elk River the red drift lacks the overlying mantle of gray drift found in much of Sherburne County. The most accessible bank seen is a mile east of Elk River. The samples taken here slake in four minutes and show a low plasticity and a shrinkage of 1 per cent on drying. The tensile strength is about 120 pounds to the square inch. Burning tests gave the following results:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
06	Red	1	16
04	.....do	1	15
02	.....do	2	13
1	.....do	3	10
3	.....do	3	9
5	Brown	5	4

The clay becomes hard at cone 02 (2,030° F.) and reaches viscosity at cone 6 (2,282° F.). Where this drift is available there is little need of using the gray drift. Two miles south of East St. Cloud, just across Mississippi River from some brickyards in Stearns

County, a brickyard at one time produced cream-colored brick from yellowish laminated clay.

SIBLEY COUNTY.

Gray drift covers nearly all of Sibley County, except along Minnesota River, where alluvium is found. The alluvium makes fair red brick. At Henderson 50 per cent of sand from the bed of the river is added to the richer clay for making sand-mold brick. The clay without the additional sand shows medium plasticity with 23 per cent of water and shrinks 7 per cent on drying. The tensile strength is 100 pounds to the square inch. Burning tests resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
04	Salmon	3	24
02	.....do	5	16
01	Red	9	3
1	.....do		

The clay is hard after heating to cone 03 (1,994° F.) and reaches viscosity at cone 2 (2,138° F.). The plant can produce about 10,000 red brick a day.

STEARNS COUNTY.

Clay-bearing formations:
- Recent: Lake clay.
- Pleistocene:
  - Gray lake and river clays.
  - Red drift.
  - Gray drift.
- Cretaceous:
  - Upper shale.
  - Basal clay.
- Archean: Residual.

In Stearns County good common brick are made from the laminated glacial clays south of St. Cloud and from the recent lake clays of Eden Lake. The drift is less satisfactory. Attempts were made to use it near St. Cloud, Collegeville, and Richmond. Older formations which have not been much developed are worthy of investigation.

Just west of Richmond, at the west end of a wagon bridge over Sauk River, is an exposure of the Cretaceous beds that has been explored by shafts and tunnels in search of coal. Gray shales crop out above water level. A shaft about 100 feet deep, after passing through a large mass of basal Cretaceous conglomeratic formation and below an underlying white gritty clay retaining some traces of granitoid texture, reached granite. The geologic section resembles that exposed in Redwood County. The clay is probably decayed granite of Archean age. It is plastic and has an air shrinkage of 4 per cent. At cone 04 (1,958° F.) it is buff and is too hard to be scratched with a knife. At cone 13 (2,534° F.) it is purple, but is still undeformed and very porous.

The bottom of the basal conglomeratic clay is below water level in the river, and the overlying Cretaceous shale is exposed for many feet above. The hard white clay just at water level was tested by an auger and found to be at least 13 feet thick, half of it above water level. The exact line between the Cretaceous clay and the underlying Archean can not be determined, but both of them are of similar refractory character. The concretionary phase was tested by Oliver Bowles, with the following result, indicating the presence of some highly aluminous mineral, such as bauxite:

Partial analysis of concretionary clay from Richmond.

Silica	40.61
Alumina	40.88
Iron oxide	.82
Loss on ignition	15.91

The dark-gray shale contains some small lignite layers. Some shafts in the hill west of the river passed through a 6-inch layer

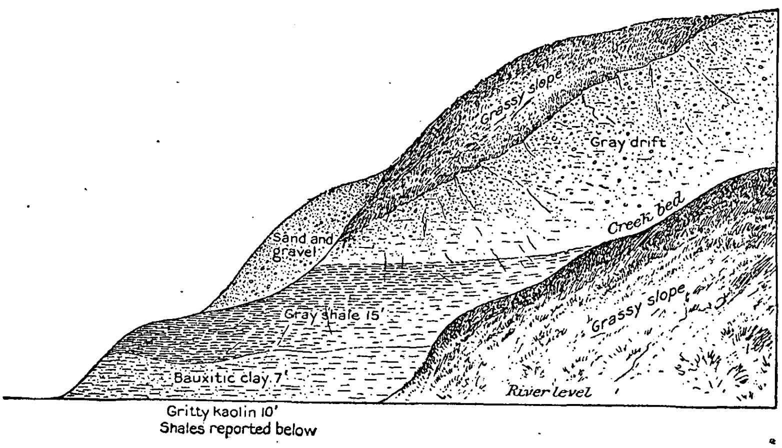


FIGURE 38.—Geologic section west of Richmond.

of lignite inclosed in blue clay that extended to a depth of 50 feet. (See fig. 38.)

Shale of the same general appearance was observed 2 miles north of Richmond in a ravine. It slakes in three minutes and is fairly plastic though somewhat waxy in feeling, apparently on account of included mica scales. It requires 16 per cent of water for molding and has a tensile strength of over 200 pounds to the square inch.

Burning tests by the Minnesota School of Mines experiment station resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
011	Salmon	0	15
07	....do	1	14
05	....do	1	13
02	....do	3	7
1	Red	....	....

The clay becomes too hard to be scratched with a knife before reaching cone 011 (1,688° F.), and if carefully burned can be heated to cone 1 (2,102° F.) without deformation. Organic matter, however, causes black cores, with great swelling and cracking, if the clay is not thoroughly oxidized. The range of vitrification is sufficient to make it quite safe to burn this clay to a dense product, but its low fusion temperature makes it less desirable as a binder for the nonplastic kaolins which underlie it.

About 3 miles south of St. Cloud, along the west bank of the Mississippi, laminated clays occur over many acres to a depth of over 30 feet, though in much of the adjacent territory they are deeply buried under more recent deposits of sand. At this particular point a tributary stream, Threemile Creek, has washed the sand off and made enough of the clay accessible to supply a couple of brickyards. As usual, the clay has irregular pockets and layers of sand, the finer parts of which are called quicksand, and the operations have to be carefully watched or the brick will be altogether too weak. If proper attention is paid to the mixing of the plastic and sandy parts of the deposits, excellent cream-colored brick can be produced. If an auger machine is used, it may often be necessary to provide lubrication—probably with water—to prevent "ragging" the corners. The clay is fairly plastic with 29 per cent of water and shrinks 7 per cent on drying. Its tensile strength is 100 pounds to the square inch. Burning tests resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
05	Buff	1	27
03	....do	1	30
2	....do	6	21
3	....do	6	19

The clay is hard after burning to cone 03 (1,994° F.) and reaches viscosity at cone 4 (2,210° F.). Each plant has a capacity of over 20,000 brick a day. At one plant both tile and brick are made and some downdraft kilns have been installed, so that the burning of the tile can be more accurately controlled.

A little farther south an exactly similar deposit at St. Augusta was worked from 1890 to 1911.

At Collegeville brick were burned for local use in the St. John's College buildings from a small deposit of yellowish laminated clay, which is apparently surrounded by coarse gravelly drift. It may be a fragment of some larger deposit, which was caught up by the last ice sheet and deposited in the midst of a gravelly moraine. The exposure sampled contains a number of limy concretions, but the brick that have been made do not seem to be damaged by them. Though too small and inaccessible to be of much interest, the clay was tested. It shows fair plasticity with 19 per cent of water. The shrinkage on drying is 3 per cent, and the tensile strength is 110 pounds to the square inch. Burning tests resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
05	Salmon	0	20
02	Red	2	16
01	.....do	4	13
2	.....do	6	9
3	.....do	7	2

The clay is hard after burning to cone 02 (2,030° F.) and reaches viscosity at about cone 3 (2,174° F.).

Brick have been made from clay obtained at the southwest side of Albany in the banks of a stream. The clay near water level is said to be entirely free from lime pebbles and burns red, probably much like that at Collegeville. At the top of the bank the gray drift is full of limestone and unsuitable for brick manufacture without cleaning.

The gray drift has been somewhat leached of its lime contents over several acres north of Miers Grove. Thorough leaching extends to a depth of only 3 or 4 feet, and apparently the original deposit contained a great many pebbles besides those of limestone. The clay slakes in three minutes and is fairly plastic, requiring 29 per cent of water for molding. Its pebbly character keeps its tensile strength rather low—100 pounds to the square inch. Its air shrinkage, however, is nearly 7 per cent. Burning tests resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
04	Salmon	0	18
02	Red	5	14
1	.....do	7	12
3	.....do	7	11

The clay is hard after burning to cone 04 (1,958° F.) and reaches viscosity at cone 3 (2,174° F.). The plant that has been working this clay has a capacity of 20,000 brick a day. The product is a very weak red brick.

Near Paynesville a brick plant has started work on a delta deposit on the shore of Eden Lake, near the mouth of the incoming creek. The deposit has been excavated 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 to the square inch, even when rapidly dried. Burning tests resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
04	Salmon	1	22
01	Pinkish gray	2	19
3	Greenish brown	8	4
5	.....do	9	3

The clay is hard after burning to cone 01 (2,066° F.) and reaches viscosity at cone 6 (2,282° F.). The plant makes stiff-mud brick and has a capacity of 30,000 a day.

A plant is said to have been opened recently to use the drift clay at Melrose.

STEELE COUNTY.

Deep-well sections in Steele County show the Decorah and overlying shale, probably Galena, at several localities, beneath the drift, notably at Owatonna. Fire clay was reported a mile east of Owatonna, but the report could not be verified.

Half a mile west of Meriden station, on the Chicago & Northwestern Railway, and extending into Waseca County, is a deposit of clay several feet thick that extends over at least 60 acres. It resembles loess, but as it lies in a swamp and is not all exposed it may also contain some glacial and recent sediments. The clay slakes at once and shows a rather low plasticity with 27 per cent of water. It shrinks 4 per cent on drying and has a tensile strength of 150 pounds to the square inch. Burning tests resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
05	Salmon	1	29
02	.....do	1	30
1	Brown	13	6
2	Brownish gray	....	....

The vitrification is sudden, between cone 02 and cone 2. The clay does not seem to be as promising as other loess and swamp clays. An analysis by E. P. Harding, of the University of Minnesota, is given below:

Analysis of clay from Meriden.

Silica	60.00
Alumina	11.45
Iron oxides	3.90
Magnesia	4.05
Lime	6.48
Potash	4.09
Soda	2.84
Moisture	2.32

STEVENS COUNTY.

Stevens County has a cover of gray drift which, where modified or worked over as outwash, can be made into fairly good brick. This was done at Morris. At other points the drift must be cleaned. Recent lakes may contain some good clay.

SWIFT COUNTY.

Clay-bearing formations:
- Recent: Alluvium.
- Pleistocene: Gray drift.
- Archean: Residual clay.

Gray drift and associated outwash deposits are the chief source of clay in Swift County, and neither is promising for anything except common brick. Alluvium is of small extent in this county. Decomposed granite was encountered at a depth of 400 feet in drilling a well at Benson and penetrated 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 and surface wash were used for red brick but were found too full of limestone to make good products.

TODD COUNTY.

Clay-bearing formations:
- Recent: Lake clay.
- Pleistocene:
  - Gray laminated clay.
  - Outwash clay.
  - Red drift.
  - Gray drift.

Most of Todd County is covered with gray drift, and many attempts to use it have failed from common defects. The best clays are probably those of the glacial lakes and recent lakes and swamps.

The most valuable deposit of the laminated clays seems to be one on Sauk Lake, most easily reached from Sauk Center, in Stearns County, 3 or 4 miles to the south. The clay bank rises steeply from the shore of the lake to a height of 15 or 20 feet and extends several rods back under the level surface. The clay directly underlies the soil, although in some places its upper beds are sandy. Pits have been opened at numerous points along the shore, exposing sections that vary considerably. Limy concretions occur in a few places. The best clay which is reported to lie at water level is gray in color, and the main part of the bank above water level is yellowish white. Upham[1] concluded that this clay accumulated in a channel in the melting ice sheet while a large mass of ice still occupied the basin of Sauk Lake. Products made from the different parts of the bank include both red and cream-colored brick, hollow brick, terra cotta, and flower pots. Samples of the yellow and gray clays show the usual differences. The average air shrinkage is 3.5 per cent, but that of the blue clay is 5.5 per cent. An average mixture of the material in the bank was burned at the Minnesota School of Mines experiment station, with the following results:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
05	Salmon	0	21
02	.....do	1	22
2	Buff	5	14
3	.....do		

The clay is hard after burning to cone 02 (2,030° F.) and reaches viscosity at cone 3 (2,174° F.), having thus about the same range as the average gray laminated clay in other parts of Minnesota. Selected samples from different parts of the deposit differed in plasticity but were almost identical in their behavior in the fire. Mr. David Pangburn, who has taken the lead in developing the deposits and in experimenting with them, has retired, and active work on the deposit has been dropped; but plans are in progress for a reorganization, and it is thought that, in view of the amount of good clay available, shipping facilities will be provided and excellent products will be turned out.

A similar deposit on the banks of Fardens Lake, 3 miles from Little Sauk, beside Battleham Church, was opened for a kiln of brick, but there was some difficulty in drying, and the location was not favorable for continuous operation. The clay slakes in one minute and is highly plastic with 30 per cent of water. It shrinks 6 per cent on drying and has a tensile strength of 200 pounds to the square inch if carefully dried. Burning tests resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
06	Salmon	0	27
03	.....do	1	26
01	Buff	7	13
1	.....do	7	12
3	.....do	10	3

[1] Upham, Warren, Minn. Geol. and Nat. Hist. Survey Final Rept., vol. 2, p. 578, 1888.

The clay is hard after burning to cone 02 (2,030° F.) and reaches viscosity at cone 4 (2,210° F.).

Many years ago a brick plant made use of some laminated clay found along the north shore of Birch Lake, about a mile east of the town of Birch Lake, near the railroad. The deposit may be in part a relatively recent formation but is probably also in part of glacial origin. The clay is similar to those at Sauk Lake and other lakes, but its extent is much less certain.

Just southwest of Burtrum two brick plants have been built to use outwash from the red 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 has a rather low plasticity. It requires 21 per cent of water for molding, and shrinks 5 per cent on drying. Its tensile strength is nearly 200 pounds to the square inch, though somewhat less if rapidly dried. The clay burns salmon-colored at low temperatures but buff to green at higher temperatures, indicating the presence of considerable lime, probably derived from wash from the gray drift, which extends nearly up to this point. It burns hard at cone 01 (2,066° F.) and reaches viscosity at cone 4 (2,210° F.). Neither of the plants is now in operation, but their suspension is thought not to be the fault of the clay, which is fairly good for common brick.

At Clarissa Spur, near Clarissa, a plant uses a sandy laminated clay that is known to be 12 feet thick and extends over several acres, with an overburden of only 2 or 3 feet. It slakes in four minutes and has a rather low plasticity and an air shrinkage of less than 3 per cent. The tensile strength is nearly 150 pounds to the square inch. The range of vitrification is from cone 1 (2,102° F.) to cone 5 (2,246° F.) or more. The plant has a capacity of 10,000 soft-mud brick a day. Drainage causes difficulty if the whole thickness of clay is worked.

A mile or two east of Staples along the Northern Pacific Railway is a deposit of laminated clay several acres in extent that has been worked at two brick plants to a depth of 6 feet, below which it is said to contain too many limestone concretions to be of value. The plants have a combined capacity of about 40,000 common red brick a day. The clay slakes in two minutes and is highly plastic, requiring 28 per cent of water for molding. Its tensile strength is over 100 pounds to the square inch, but there is danger of cracking if the ware is rapidly dried. The air shrinkage is nearly 6 per cent. Burning tests gave the following results:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
05	Salmon	1	25
03	.....do	2	23
04	.....do	2	23
1	Greenish brown		

The clay becomes hard at cone 03 (1,994° F.) and reaches viscosity at cone 1 (2,102° F.).

In the morainic belts there are a great many swampy kettle holes where the wash from the gray drift has accumulated. Two miles west of Long Prairie a brickyard has used some small deposits of this sort for common red brick, but the deposits are nearly worked out and no others so easily accessible are known. Another such deposit about half a mile east of Beaver Bend was used for a kiln of brick several years ago, but it contains too many limestone pebbles and is too small to be of much promise.

TRAVERSE COUNTY.

Clay-bearing formations {Pleistocene: Gray drift. / Cretaceous: Clay.}

Gray drift, somewhat modified by Lake Agassiz, is the chief available clay in Traverse County. A very large part of the county is underlain by Cretaceous clay, most of which, however, is covered with glacial drift and is inaccessible. Just across the river in South Dakota are some exposures, reported by Mr. A. Parker, of Browns Valley, in which the clay is at least 40 feet thick and extends for miles along the valley. The clay is stratified with blue and yellow layers, and, where sampled, underlies about 20 feet of glacial drift. It is favorably situated for excavation but is a mile from any railroad. The clay slakes in four minutes and is highly plastic, requiring 34 per cent of water for molding. Its tensile strength is over 100 pounds to the square inch, even when it is rapidly dried. It develops considerable adhesive strength after being slightly compressed, even if it has been separated into parts as in the auger machine, being one of the few clays tested that showed this desirable quality. Its air shrinkage is 11 per cent. Burning tests at the Minnesota School of Mines experiment station resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
010	Salmon	1	15
06	.....do	4	9
02	Red	7	3
2	.....do	7	3
3	.....do		

The clay becomes too hard to be scratched with a knife somewhat below cone 010 (1,742° F.) and is still undeformed at cone 3 (2,174° F.), giving a range of vitrification of about 400°. If rapidly heated the organic matter causes swelling and the formation of black cores, but this can be easily avoided by thorough oxidation. The analysis of the clay is given on page 91.

WABASHA COUNTY.

Clay-bearing formations:
- Recent: Alluvium.
- Pleistocene:
  - Loess.
  - Gray drift.
- Cretaceous: Clay (?).

At Wabasha a plant was in operation for about 20 years on loess loam, which covers at least 40 acres to a depth of 4 or 5 feet on a terrace of Mississippi River. Although the material is rather sandy, it produced a good red brick. The plant has averaged about 500,000 brick a year, but work was stopped several years ago on account of poor market conditions.

Half a mile from Elgin station loess loam, locally 12 feet thick, overlies a deposit of stratified sand in an area of 25 or 30 acres. A small hand-mold brick plant has been in operation here for over 30 years, producing about 250,000 brick a season. A similar deposit occurs near the station at Plainview, and the material was used for a time in a similar plant. (See also fig. 9, p. 99.)

The alluvial clays along the Mississippi have never been worked and are not likely to be of much value. Gray drift occurs in most of Wabasha County but is inferior to the loess and alluvium.

Cretaceous clays probably exist in this county, but no such clay has been seen in place. Small pieces of clay similar to the Cretaceous clays of Belle Chester and Clay Bank were observed in the glacial drift at numerous localities. It is not unlikely that careful prospecting would result in the discovery of local deposits of Cretaceous clay in the northern part of the county, particularly in the region near Oak Center.

WADENA COUNTY.

Several attempts have been made to use the common gray drift in Wadena County, but the limestone pebbles caused the usual difficulty, and no one has used the process necessary for removing them.

WASECA COUNTY.

Small yards at several localities in Waseca County formerly manufactured common brick from the gray drift. It may be possible to find glacial or recent clays worth developing. The Decorah shale is buried deeply under the drift.

The loesslike clay west of Meriden has been described under Steele County (pp. 237–238).

A deposit of the gray drift in the northern part of Waseca County, 1½ miles south of Waterville (Le Sueur County), along the Chicago Great Western Railroad, contains very few pebbles and may have been formed as a sort of outwash. The clay, with some sand added, was successfully used for brick about 25 years ago. It slakes in two minutes and is fairly plastic with 30 per cent of water. It shrinks 5 per cent on drying and has a tensile strength of 150 pounds to the square inch. Burning tests resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
04	Salmon	1	25
01	.....do	5	18
1	.....do	11	2

The clay is not very hard until heated to a temperature of cone 02 (2,030° F.) and becomes viscous at about cone 2 (2,138° F.).

WASHINGTON COUNTY.

Clay-bearing formations:
- Recent: Lake clay.
- Pleistocene:
  - Red laminated clay.
  - Red and gray drift.

All the clays of Washington County have been used, but few deposits are favorably situated for development.

The Forest Lake Brick & Tile Co. had a pit just south of Forest Lake along the Northern Pacific Railway in an extensive deposit of gray drift, which is a little less pebbly than usual. At the plant the clay was ground but not cleaned from the lime. The capacity is about 10,000 red brick a day. The clay slakes very promptly and shows a fairly high plasticity. Its air shrinkage is 4 per cent and its tensile strength about 125 pounds to the square inch. Burning tests by the Minnesota School of Mines experiment station resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
04	Light red	0	16
02	Red	1	14
01	.....do	1	12
2	.....do	....	....

The clay becomes hard at cone 03 (1,994° F.) and shows no sign of becoming viscous at cone 3 (2,174° F.). Lime particles shattered the brick at all these temperatures. Although this clay might be improved by the removal of limestone pebbles, it appears to be furnishing a satisfactory product by simple grinding. It must, however, be burned to a fairly high temperature or the lime particles will greatly weaken the product. Two round downdraft kilns are in use at the plant.

The plant at first used red drift from the other side of the lake, several miles away. This material had to be loaded on cars, hauled a quarter of a mile, and reloaded on a barge for transportation across the lake. Owing to the great expense of getting the material in this way the red drift was abandoned in favor of the more accessible gray drift. A sample, however, indicates the excellent quality of the red drift of the region. It slakes at once and, after the gravel has been crushed to 40-mesh, has a fairly high plasticity. The tensile strength is considerably over 100 pounds to the square inch, even after rapid drying. The water required for molding is 20 per cent, and the air shrinkage is 4.5 per cent. Burning tests resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
07	Red	1	15
05	....do	2	14
1	....do	7	5
3	....do	8	4

The clay becomes hard at cone 06 (1,886° F.) and is approaching viscosity at cone 3 (2,174° F.).

A sample of the red drift 2 or 3 miles south of Afton, obtained by Mr. Frank Squyers, seemed to be much less pebbly than usual and showed the usual satisfactory range of vitrification. The material may have been reworked by recent river action. It is not especially accessible to any of the large markets but is of good quality.

At Stillwater deposits of red laminated clay occur along Browns Creek just above its mouth. These were described by Winchell as tripoli (for analyses and reference see p. 97), because they were rather more gritty than most of the laminated deposits discovered. Winchell, however, notes the probability of their having an origin similar to that of the laminated clays at St. Paul. The extent of the deposits has not been accurately determined, but many similar deposits are exposed farther north along St. Croix River. The clay slakes in one 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 to the square inch, but the clay can be rapidly dried without injury and shows considerable strength even after having been cut in two if again pressed together in the plastic state. This would seem to indicate successful working with the auger machine, but the plasticity is hardly sufficient. The air shrinkage is only 2 per cent. Burning tests at the Minnesota School of Mines experiment station resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
05	Salmon	1	20
03	....do	2	17
01	Red	5	10
1	....do	6	3
2	....do	8	2

The clay becomes hard at cone 02 (2,030° F.) and reaches viscosity at cone 2 (2,138° F.). This is the type of clay used at Menomonie, Wis., for excellent building brick. These Minnesota clays might make as good brick as those now brought from other States.

Just south of Stillwater, on the shores of Lily Lake, are deposits of lake clays of a quality suitable for hard common red brick. They are known to be 10 feet thick over several acres. They are not convenient to any market, as no railroad comes near and a steep hill lies between them and Stillwater. The clay is, however, of excellent quality. It slakes in two 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 to the square inch. Burning tests at the Minnesota School of Mines experiment station resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
06	Salmon	1	14
02	Red	2	12
1	....do	4	9
3	....do	5	6
5	....do	6	6

The clay is hard after burning to cone 02 (2,030° F.) and reaches viscosity at cone 5 (2,246° F.).

WATONWAN COUNTY.

Clay-bearing formations { Recent: Lake and swamp clays.
Pleistocene: Gray drift.

In Watonwan County most of the surface material under the soil is the common gray drift, but the kettle holes and swampy depressions contain clay washed from the gray-drift hills. The drift in sec. 13, T. 106 N., R. 32 W., near St. James, would have to be cleaned of the limestone pebbles to be used successfully for brick or tile. It is almost identical with that used at Hutchinson.

There are several deposits of swamp clay in the midst of the drift area, and some of them seem to be of excellent quality. A deposit at Low Lake, 2 miles northeast of Madelia, was utilized in a brickyard operated about 1900. Sand was mixed with the clay, and the product was a light-red brick. At Odin a similar deposit 16 feet thick and many acres in extent has been thoroughly prospected but has not yet been developed. Both these clays slake promptly and are fairly plastic with 24 per cent of water. Their air shrinkage is 5 per cent and their tensile strength over 100 pounds to the square inch. Burning tests at the Minnesota School of Mines experiment station resulted as follows:

Clay near Madelia.

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
05	Salmon	0	26
03	.....do	1	24
1	.....do	2	21
3	Brownish gray	3	14
5	Yellowish gray	....	....

Clay from Odin.

Cone No.	Color.	Shrinkage.	Absorption.
06	Red	0	15
03	.....do	1	14
01	.....do	3	11
2	.....do	4	7
3	.....do	5	3

Both clays show a fair range of vitrification; that from Odin is hard after burning to cone 05 (1,922° F.) and reaches viscosity about cone 3 (2,174° F.).

WILKIN COUNTY.

Wilkin County has only the common gray drift, modified north of Breckenridge by Lake Agassiz and Red River.

About a mile north of Breckenridge a brickyard has been operated at times since 1880 on clay that crops out in the east bank of the river in places with a thickness of 30 feet. Where exposed and weathered the clay is highly plastic and requires 23 per cent of water for molding. The air shrinkage is 14 per cent, and the clay has so strong a tendency to crack in drying that its tensile strength is likely to be small. It burns hard at an unusually low temperature, below 1,700° F., and on being burned to higher temperatures tends still more to crack. With careful drying and slow oxidation it has a good range of vitrification and might be burned to a vitrified product.

WINONA COUNTY.

Clay-bearing formations:
- Recent: Alluvial clays.
- Pleistocene:
  - Loess clays.
  - Gray laminated clays.
- Ordovician: Decorah shale.
- Cambrian: Shale of St. Lawrence formation.

There is very little drift in Winona County. The chief formation of value for brick and tile is the loess loam, which forms a mantle covering the entire county, except along the bottoms of the stream valleys, where it has either been washed away or modified by stream action. Even in these valleys, especially near Mississippi River, the loess thickly covers many terraces and lower valley slopes. The best deposit observed is at Dresbach, where it was worked for about 30 years in the manufacture of common red brick and where at one time four large brickyards were using it. No work has been done at this locality for several years. Other workable deposits are at Winona, Dakota, Homer, Lewiston, Utica, and St. Charles. (See fig. 9, p. 99.)

At Homer, in secs. 32 and 33, T. 107 N., R. 6 W., an undeveloped deposit of loess on a terrace on the side of a ravine is 4 or 5 feet thick over at least 6 acres and is probably much more extensive. The clay slakes in one minute and shows a fairly high plasticity. It requires 24 per cent of water for molding and shrinks 5 per cent on drying. Burning tests at the Minnesota School of Mines experiment station resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
05	Red	1	20
02	do	2	17
01	do	4	14
2	do	5	13
5	do	8	5

The clay becomes too hard to be scratched with a knife at cone 02 (2,030° F.) and reaches viscosity at about cone 6 (2,282° F.). It is not known whether the clay is abundant enough to warrant a large plant, but its quality seems to insure very excellent hard-burned or even vitrified red brick.

About 4 miles northwest of Winona loess loam covering more than 100 acres is exposed to depths of 8 to 20 feet. The clay is irregularly sandy and contains some streaks of gravel. A plant of medium grade is turning out red brick of good quality at the rate of about 35,000 a day.

Three miles southwest of Winona a deposit at a brickyard shows the following section:

Section 3 miles southwest of Winona.

	Ft.	in.
Soil		6
Sandy yellow loess	2	0
Very plastic red clay	1	2
Plastic yellow massive clay	3	6
Stratified yellow sandy clay	4	0

A sample taken to include all of the section except the soil slakes in a very few minutes and develops a fairly high plasticity. The mixture requires 36 per cent of water for molding and has an air shrinkage of 10 per cent, resulting in a strong tendency to crack on drying. When properly burned it forms red brick which becomes hard at cone 010 (1,742° F.). If the clay is rapidly burned, the organic matter will develop black cores and destroy the brick, but if slowly burned it does not become viscous at a temperature of cone 2 (2,138° F.). It has thus a range of vitrification of about 400° F. and can be safely burned to a fairly good hard product.

Near the deposit just described alluvium has accumulated along Burns Creek to a depth of 12 to 14 feet over more than 40 acres. The clay is blue-black and very plastic and in many places is quite free from pebbles. It is used for mixing with other clays in the neighborhood. The plant has the disadvantage of being distant from the railroad. The clay slakes in four minutes and requires 23 per cent of water for molding. Its air shrinkage is 2 per cent and its tensile strength 200 pounds to the square inch. Burning tests resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
02	Salmon	0	27
01	....do	0	25
2	Brown	2	20
4	....do	7	13
5	....do	8	....

The clay is hard after burning to cone 01 (2,066° F.) and reaches viscosity at cone 5 (2,246° F.). Brick are produced at the rate of 3,000,000 a season.

The Decorah shale occurs in a small area in the southwest corner of the county, near St. Charles, where it is 40 feet thick under 30 feet of drift and might be developed. It has the plasticity, strength, and generally good working behavior characteristic of the Decorah shale. Burning tests resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
010	Salmon	7	10
06	Red	11	3
04	.....do		
02	.....do		

The clay is hard after burning to cone 010 (1,742° F.), above which it tends to develop black cores and bleb structure. However, by oxidizing very thoroughly the vitrification might be carried along to a very low porosity.

The shales of the St. Lawrence formation crop out at Dresbach but are too thin to be of value. A sample taken does not slake or develop much plasticity or tensile strength. In burning it retains a porosity of 20 per cent up to cone 4, when it becomes gray and hard.

WRIGHT COUNTY.

Clay-bearing formations:
- Recent:
  - Alluvium.
  - Lake and swamp beds.
- Pleistocene:
  - Gray laminated clay.
  - Gray drift.

Gray drift covers most of Wright County. At Otsego an attempt to use it failed because of the limestone it contained. Two or three attempts have been made to use the deposits around Buffalo, some of which are of a peculiar type, described below. Brick have been made from the upper leached portion of the drift in places where it is relatively free from limestone pebbles. Laminated clays are more promising and have been used at Dayton, Hasty, and Annandale.

At Dayton, near the mouth of Crow River, laminated clays of the usual character have accumulated in great quantity. Prosper Vassar's brickyard has been operating on these clays since 1880 but has thus far used only the upper leached yellow portion of the deposit, which contains a few limy concretions but has yielded excellent common brick for local use. The plant has a stiff-mud machine and makes 30,000 brick a day. The yellow clay is fairly plastic with 24 per cent of water. It shrinks 4 per cent on drying and has a tensile strength of 125 pounds to the square inch. It was burned at the Minnesota School of Mines experiment station, with the following results:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
04	Buff	0	34
1	.....do	2	30
3	.....do	6	22
4	.....do	12	10
5	.....do	15	4
6	Yellow		

The clay becomes hard at cone 1 (2,102° F.) and shows signs of viscosity at cone 6 (2,282° F.).

The underlying blue clay is more plastic, requires more water for molding, shrinks about three times as much, and has a lower temperature of vitrification, apparently reaching viscosity before the yellow clay becomes hard. It has a strong tendency to form black cores, being so fine grained that oxidation is very slow.

Up the river from this deposit there is good laminated clay at St. Cloud, but between the good clays at Dayton and St. Cloud, a mile or more from Hasty, is a deposit of laminated clay which appears to be similar but caused trouble at the plant by checking. The sample taken slakes in three 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 of not over 10 pounds to the square inch, indicating that the shrinkage caused cracks that weakened it. Burning tests gave the following results:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
06	Salmon	2	22
05	....do	2	24
03	....do	3	21
1	Buff	9	5
2	....do	10	3

The clay becomes hard at cone 06 (1,886° F.) and reaches viscosity at cone 2 (2,138° F.). Apparently its only serious drawback is its tendency to crack on drying, though there may be some serious trouble from the laminated structure produced by the auger machine. These difficulties could be easily remedied if a more sandy layer could be found for mixing with the clay now used. The plasticity is high enough, and sand would improve the clay in several ways.

The Annandale Brick & Tile Co. has built a plant a mile east of Annandale on the Minneapolis, St. Paul & Sault Ste. Marie Railway, to make use of a deposit of laminated clay known to extend over several acres to a depth of at least 15 feet. The clay is covered with only a thin soil and has very few limy or ferruginous concretions. When traced for 200 yards eastward along the railway it is found to be very much sandier and not so good. The clay used was sandy enough, so that this very sandy part of the deposit remained untouched. The working and burning qualities of the clay seem to be excellent, but some difficulty has been encountered at the plant in getting the clay to dry without cracking and thus losing its strength. The water of plasticity is 31 per cent, and the shrinkage on drying is 4 per cent. Burning tests resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
04	Salmon	1	28
02	.....do	5	25
01	.....do	6	18
2	Brown		

The clay is hard after burning to cone 02 (2,030° F.) and reaches viscosity at about cone 2 (2,138° F.).

In sec. 27, T. 120 N., R. 25 W., about 2½ miles from Buffalo and 1½ miles from the railroad, a rather extensive swamp has been drained by a State ditch, the material thrown out from which contains fragments of shale in great abundance and is relatively free from limestone pebbles. Its pebbly texture shows that it is not a lake or swamp deposit, but it nevertheless differs noticeably from the average gray drift. Such material has not been noted in any other part of Minnesota except near Alexandria. It 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 to the square inch, though it checks rather badly on drying. Burning tests by the Minnesota School of Mines experiment station resulted as follows:

Cone No.	Color.	Shrinkage.	Absorption.
		Per cent.	*Per cent.*
04	Red	1	17
02	.....do	1	16
1	.....do	2	14
3	.....do	4	11
4	.....do	5	10
5	.....do	5	9

The clay becomes hard at cone 02 (2,030° F.) and shows no sign of becoming viscous at cone 5 (2,246° F.), having thus a range of over 200° during vitrification. The cross fracture of a well-burned brick gives every indication that it is good material for paving brick, and simple laboratory estimates show that it is both hard and tough. The deposit is recommended for further exploration and testing.

A lake deposit occurs along the shores of Lake Mary, 6 miles from the station of Howard Lake. The clay was mixed with coarse sand, which is available in the same neighborhood, and was manufactured into red brick by a soft-mud process. The plant had a capacity of 250,000 brick a year but is now abandoned.

At Monticello brick were made some years ago from a very sandy and probably alluvial clay in the banks of Mississippi River. The deposit seems to contain less than 20 per cent of clay substance, and the brick produced were common red brick of very 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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