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George M. Schwartz, Director

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PRELIMINARY SURVEY OF BLOATING CLAYS AND SHALES IN MINNESOTA

by

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ABSTRACT

This report is a description of a preliminary study of bloating clays and shales of the state of Minnesota, by the Minnesota Geological Survey in the years 1955-1956. The work was inspired by an increasing industrial demand for local expanded aggregate. Though the lack of time did not permit a study of all the clays and shales of the state over 543 samples from 188 localities representing 40 of 87 counties of the state were tested. Both old and newly collected samples were used in the study. Special attention was paid to the southeastern part of the state, particularly the vicinity of the Twin Cities. The formations tested range in age from Precambrian to Recent.

Bloating tests were made by heating in an electrical furnace a dozen small fragments of each sample in a 3" diameter scorifying dish. In order to prevent "popping" the dishes were covered with small asbestos sheets. The main part of the testing was designed to eliminate the definitely nonbloating clays and determine those of possible satisfactory characteristics. Such elimination is considered as the main result of laboratory testing which can be fully applied to the industrial bloating. Other characteristics such as "bloating limits", and temperatures of bloating, depend greatly on kiln atmosphere, type of heating, and degree of weathering of the clay. The temperature, and atmosphere, obtained in the laboratory is not directly comparable with the corresponding conditions in an industrial process.

All the samples were tested at an average temperature of 1280°C(2336°F) (maximal temperature in a few cases was 1300°C = 2372 °F) during 7 min. time intervals in room atmosphere. After the testing, all the samples which showed bloating properties were found to be overbloated, hence their upper bloating limit, even in an electrical furnace and in normal atmosphere is below the above temperature. Industrial bloating of the same samples in a kiln atmosphere would take place at a lower temperature. Reproducibility of the experiments was quite satisfactory, but showed certain differences for samples prepared in different ways, particularly changes of the interior texture of samples by pulverizing and molding into briquets apparently greatly affects the bloating properties.

The following conclusions about bloating properties of different types of Minnesota clays and shales seem justified:

1. The Decorah shale which outcrops in the southeastern part of the state generally bloats well. The shale, however, contains numerous limestone layers and lenses which produce quicklime. Screening to eliminate the limestone would be necessary for industrial use of the shale. The shale seems to be the only source of clays for commercial bloating in that part of the state.

2. Numerous small deposits of probably Cretaceous clays scattered all over the southeastern part of the state are mainly of a non-bloating type.

3. Residual Precambrian and basal Cretaceous clays which outcrop along the Minnesota River Valley are of a non-bloating type.

4. Some samples of gray glacial till of different ages bloat satisfactorily. The use of the till will require, however, separation of numerous boulders and pebbles.

5. Boulders and pebbles have been eliminated in clay deposits of ancient glacial lakes. Many such clays have good bloating properties.

6. Cretaceous shales from Brown and Itasca Counties bloat satisfactorily.

7. Fond du Lac shales of Precambrian age are of a non-bloating type, but according to the data obtained by the University of Minnesota Mines Experiment Station, Virgina slate of Precambrian age bloats satisfactorily. Northing is known of the bloating properties of the Precambrian Cuyuna and Thomson "slates."

The best chances for deposits of bloating clays for industrial purposes seem to occur in Cretaceous beds of Brown County, in glacial lake deposits, and possibly in the Decorah formation.

GENERAL STATEMENT

Bloating is the property of certain clays and shales to expand at a high temperature. The temperature interval over which the bloating of a sample occurs is called its bloating range. Bloated shales and clays are used together with other porous treated and untreated natural products such as pumice, scoria, and industrial byproducts such as slags, and cinders for lightweight aggregates. Because of wide use and of growing demand for such aggregates a nation wide search for bloating shales and clays has taken place in the recent years.

The following report is a result of a preliminary regional study of bloating properties of Minnesota clays and shales made by the Minnesota Geological Survey during 1955-1956 in response to a constantly increasing demand for local light-weight aggregate. Similar studies have been made in several neighboring states (Cole and Zetterstrom 1954, Manz 1954) and some have led to the development of a local light-weight aggregate industry.

A previous study in Minnesota by C. M. Riley proved the presence of good bloating shales and clays. It was decided, therefore, that a thorough sampling of many exposures should be carried out to supplement this earlier work. Special attention was paid to areas located close to the main demand for light-weight aggregates, the Twin Cities, but an attempt was made also to obtain regional information on the distribution of bloating clays. A lack of time did not permit field sampling and bloating tests of all clays. To partially fill this gap many samples in the Minnesota Geological Survey collection were tested.

Altogether 543 samples from 188 locations representing 40 of 87 counties of the state were bloated during the investigation.

The general requirements for bloating clays or shales include: (Cole and Zetterstrom 1954, Manz 1954, Riley 1950).

1. Good bloating properties of raw materials:
   a. Bloating at low temperatures to insure low fuel expense.
   b. Wide range of bloating, which simplifies technology, particularly temperature control of the process. Cole and Zetterstrom report bloating ranges of from 50 to 110°C (from 90 to 198°F) and in a few cases up to 200°C (360°F).
   c. Light weight of the products obtained. Bulk density of aggregates made of the products should not be above 50 pounds to the cubic foot compared to 150 lb. for ordinary concrete with sand and gravel aggregate.
   d. Sufficient strength of pellets to insure strength of aggregates.
   e. Rounded shape of bloated particles to insure good work ability.
   f. Low water absorbtion of particles (closed pores) to prevent dehydration of cement.
   g. Sufficient quantities of fine and coarse particles (well-graded mixture) to insure good workability of concrete.
   h. Chemical inertness to insure strength of concrete; particularly objectionable is the presence of lime.
2. Proper geographical and geological location of the deposit to insure low production cost.
   a. Location close to market areas to reduce transportation costs.
   b. Presence of proper transportation facilities such as railroads and highways.
   c. Presence of cheap fuel, i.e. location near gas or pipe line.
   d. Sufficient size of deposit to insure raw materials for several years, for example, two million yards of shale to insure a supply for 20 years at the rate of 100,000 yards per year.
   e. Sufficient thickness of bloating shales or clays and uniform bloating qualities.
   f. Thin overburden (mostly not over 35-40 feet).
   g. Location above ground water level, or presence of proper conditions for drainage.

Most deposits usually do not possess all of these desirable properties. Clays and shales have many other uses to which some of the above requirements do not apply.

ACKNOWLEDGEMENTS

The writers are greatly indebted to:

Prof. George A. Thiel, Department of Geology, University of Minnesota, who gave freely of his detailed knowledge of the stratigraphy of Minnesota in planning and carrying out the work.

Mr. Henry H. Wade, Director of the Mines Experiment Station of the University of Minnesota for information dealing with bloating of the Virginia slate and drift clays.

All partial chemical analyses of the Decorah Shale (Table 2) were made by Mr. Vernon Bye through the generous cooperation of Mr. H. Wade.

Mr. L. D. Zetterstrom gave several important suggestions dealing with operation of the bloating furnace and methods of bloating.

PREVIOUS WORK

The first study of clay and shale deposits of the state of Minnesota was made by the State Geologist N. H. Winchell and his co-workers. The results of this early and general investigation are published in the Annual Reports of the State Geologist and summarized in "The Geology of Minnesota Final Report" Vol. I to VI, 1872-1901. Later studies of the distribution, origin, and properties of Minnesota clays and shales was carried out by F. F. Grout and E. K. Soper (1914, 1919). Though clays were considered mostly from the standpoint of the brick and ceramic industry, their papers contain valuable information on the distribution and type of clay deposits and locations of old clay pits. The locations are also shown on the "Map of Mineral Resources of Minnesota" compiled by Schwartz and Prokopovich in 1956.

The first discovery of bloating shales in Minnesota was made by Mrs. Ruth Lawrence, the Director of the University of Minnesota Art Gallery. A more detailed study was by Charles M. Riley in 1948-49 and released as a Minnesota Geological Survey Summary Report No. 5 in July, 1950. The study was of a preliminary nature and included 70 samples collected from 36 localities. Forty-six samples of the Decorah shale, 12 samples of Glacial Lake clays, 8 samples of Cretaceous clays, and 4 samples of loess were collected as channel samples, pulverized, mixed, and cast into small briquetts which were bloated in a specially built electric furnace. The highest bloating temperature used in the tests was 2300°F (1260°C). Among 70 samples tested, 17 were considered as bloaters with the bloating temperature ranging from 2200 to 2300°F (1205-1260°C). Decorah shale furnished most of the samples which bloated but some bloating occurred also in loess and glacial clays, but none of the samples of Cretaceous clays bloated. Decorah shale, particularly deposits at the Twin City brick yard in St. Paul, at Mendota bridge in Dakota County, and near Zumbrota in Goodhue County were pinpointed as the most promising for further study.

METHODS OF STUDY

Sampling: It is well established that not all clays and shales have bloating properties. Some of them are too refractory and others melt rapidly without liberation and trapping of essential amounts of gases which are necessary for bloating (Cole and Zetterstrom 1954). The first stage of a regional study of bloating clays should, therefore, be the collecting of the necessary number of representative samples which are characteristic of geologically different kinds of deposits and of the same types of deposits in different areas. Of the 543 samples tested 137 were collected by N. Prokopovich in 1955 in the southeastern part of the state; 245 samples were collected by K. F. Bickford in 1947 from natural and artificial exposures of residual Precambrian and basal Cretaceous clays mainly along the Minnesota River Valley; Edward Bradley collected 97 samples in 1947-48 from various parts of the state, and 17 samples were collected by others. All available samples used by Riley (48 in number) were rebloated in order to compare the two methods of bloating.

The samples collected by Prokopovich were taken as a "grab" or spot-sample mostly from the Decorah shale which was considered as the only possible commercial bloating material in the southeastern part of the state. Principal attention was paid to the areas located close to railroad lines and highways. A previously unknown deposit of the shale was found in the central part of Dakota County (sample 90). Several definitely non-commercial shale beds and other formations were also sampled in order to obtain more complete data on the nature and distribution of clays that bloat. Because of the preliminary nature of the investigation no special excavation or drilling was used to obtain samples but a few hand auger samples were collected. Most of the samples were picked from natural outcrops, road cuts, or, in case of the Decorah shale, commonly from overburden of quarries in the Platteville limestone. At several places the shale was definitely weathered and discolored by oxidation to a light brown color. The effect of weathering on bloating was studied in samples from two locations (51 and 52) near Rochester. Test bloating of weathered and unweathered shale showed that weathering increases bloating properties and decreases the temperature of bloating. For example, bloating of fresh Decorah shale in a reducing atmosphere at 1950°C produced pellets with a density (gm. per c.c.) of 1.5 to 1.7. Similar, but weathered shale produced pellets with density of 0.7 to 0.8. Fresh Decorah shale in a normal atmosphere at 1010°C produced pellets with a density over 1.6. Weathered shale under similar conditions at a temperature of 950°C produced pellets with an average density of 1.4 (1.2 to 1.7). These facts should be taken into consideration during detailed prospecting and evaluation of data obtained by surface sampling which is commonly of weathered beds. The reasons for the changes during weathering are uncertain. Weathering may change the texture of the shale and introduce some additional substances which aid the reduction of iron at a high temperature.

The age of the samples studied during the present investigation is shown in the following tabulation.

Formation	Number of samples studied
Quaternary, undifferentiated	1
Recent	8
Loess	4
Glacial Lake clays	49
Valders Drift	1
Wisconsin Red drift	8
Wisconsin Gray drift	27
Kansan Gray drift	8
Nebraskan Gray drift	1
Cretaceous	143
Residual Paleozoic clays	3
Devonian	2
Maquoketa formation	4
Prosser formation	3
Decorah shale	125
Platteville formation	11
Glenwood formation	6
Shakopee formation	2
Blue Earth formation	2
Residual Precambrian clays	131
Precambrian (fresh rock)	3

Preparation of Samples- All samples were briefly described before bloating and tested for carbonate with hydrochloric acid. Some of the samples collected earlier had been studied petrographically and chamically and results are included in this report. Numerous partial chemical analyses of Decorah shale were available (Prokopovich and Schwartz, 1956). See Table 3.

During the first study of bloating clays of Minnesota by Riley (1950) all samples were pulverized, screened through a 60 mesh sieve and cast into small briquets 1.5 x 0.25" in size. This method of preparation takes a long time, but insures a good average mixture and permits the use of channel samples. It is believed, however, that such preparation does not give a true picture of the bloating properties of clays and is not comparable with commercial bloating.

In bloating tests by Cole and Zetterstrom (1954, Manz 1954) samples were crushed to a size below a 3 mesh and above a 4 mesh screen (below 0.265" and above 0.187:). About the same size of particles were used in the present study. According to Cole and Zetterstrom this method of preparation more closely approximated rotary kiln feed and, in a case of heterogeneous material, gives a better indication of the quality of the bloated material. A comparison of Riley's tests on 48 samples and the present tests on the same samples are given in Table 1. Among the 48 samples were 17 for which results differed by the two methods. Fourteen samples were reported by Riley as non-bloating but bloated well during the present testing. The high temperature used during the present investigation could be only partially responsible for this difference. Two loess samples which were reported by Riley to bloat did not bloat during the present testing. Probably a change in the texture of clay during pulverizing and briqueting is responsible for the bloating of loess.

TABLE I

Comparison of two methods of bloating of the same samples

Sample		Bloated as small briquets up to 2300°F; Riley 1950		Bloated as rock fragments at 1280°C (2336°F) present investigation	
Number in this report	Formation	Riley's #	Degree of bloating	Specific gravity	Degree of bloating
7d	Decorah Shale	R-1	Nonbloating	-1	Bloated
7c	" "	R-2	"	+1	"
7e	" "	R-3	"	+1	Nonbloating
22b	" "	R-4-4	Bloated at 2200°F	-1	Bloated
88a	" "	R 5-1	Bloated at 2000-2200°F	-1	Bloated
88b	" "	R 5-2	Nonbloating	-1	Bloated
82c	" "	R 6-1	Nonbloating	-1	Bloated
82b	" "	R 6-2	Nonbloating	-1	Bloated
83b	" "	R 7-1	Nonbloating	+1	Nonbloating
83a	" "	R 7-2	Nonbloating	-1	Bloated
69c	" "	R 8-1	Nonbloating	+1	Nonbloating ?
69d	" "	R 8-3	Bloated at 2000-2300°F	-1	Bloated
69e	" "	R 8-4	Nonbloating	?	Nonbloating

Sample		Bloated as small briquets up to 2300°F; Riley 1950		Bloated as rock fragments at 1280°C(2336°F) present investigation	
Number in this report	Formation	Riley's #	Degree of bloating	Specific gravity	Degree of bloating
40a	Decorah shale	R 10-1	Bloated at 2300°F	-1	Bloated
40e	" "	R 10-2	Bloated at 2300°F	-1	Bloated
69f	" "	R 8-5	Nonbloating	+1	Nonbloating
66b	Cretaceous?	R 11-1	Nonbloating	+1	Nonbloating
66c	"	R 11-2	Nonbloating	+1	Nonbloating
73c	Decorah Shale	R 12-1	Nonbloating	+1	Nonbloating
73d	" "	R 12-2	Nonbloating	+1	Nonbloating
73e	" "	R 12-3	Nonbloating	+1	Nonbloating
72	" "	R 13	Nonbloating	+1	Nonbloating
71b	" "	R 14-2	Nonbloating	+1	Nonbloating
71c	" "	R 14-3	Nonbloating	about 1	Bloated
71d	" "	R 14-4	Nonbloating	-1	Bloated
71e	" "	R 14-5	Nonbloating	-1	Bloated
74c	" "	R 18	Nonbloating	-1	Bloated
55f	" "	R 19	Nonbloating	+1	Nonbloating
42	Loess	R 20	Bloated 2300°F	+1	Nonbloating
48	Kansan gray drift	R 21-2	Bloated 2200-2300°F	+1	Nonbloating
28	Cretaceous?	R 22	Nonbloating	+1	Nonbloating
31	"	R 23	Nonbloating	+1	Nonbloating

Sample		Bloated as small briquets up to 2300°F; Riley 1950		Bloated as rock fragments at 1280°C (2336°F) present investigation	
Number in this report	Formation	Riley's #	Degree of bloating	Specific gravity	Degree of bloating
92e	Decorah Shale	R 25-1	Bloated at 2050-2250°F	-1	Bloated
92d	" "	R 25-2	Bloated at 2050-2250°F	-1	Bloated
92c	" "	R 25-3	Bloated at 2050-2250°F	-1	Bloated
92b	" "	R 25-4	Nonbloating	-1	Bloated
92a	" "	R 25-5	Nonbloating	-1	Bloated
94b	Glacial Lake clay?	R 26	Nonbloating	+1	Nonbloating
85b	Decorah Shale	R 27-1	Bloated at 2200-2300°F	-1	Bloated
85a	" "	R-27-2	Nonbloating	+1	Nonbloating
79	" "	R 29	Bloated at 2150-2300°F	-1	Bloated
70a	" "	R 30-1	Nonbloating	-1	Bloated
70b	" "	R 30-2	Nonbloating	-1	Bloated
70c	" "	R 30-3	Bloated at 2150-2250°F	-1	Bloated
65	Loess	R 32	Bloated at 2200°F	+1	Nonbloating
141	Glacial Lake	R 33	Bloated at 2150-2300°F	+1	Bloated
91d	Decorah Shale	R 34-1	Bloated at 2000-2300°F	-1	Bloated
91c	" "	R 34-2	Bloated at 2000-2300°F	-1	Bloated

Bloating Tests.--Only small scale laboratory equipment, usually an electric furnace, with a good temperature control, is commonly used for a preliminary study of bloating clays. The furnace used in the present testing was built by Charles Riley and only slightly modified during the present tests. It is an electric furnace heated by six 3/4" x 27" "Globars" operating at 220 volts and using a current of about 38 amperes. The globars heat an alundum muffle 5 x 17 x 14" in size, which is placed in a shell of porous fire bricks. The current and temperature are regulated by two rheostats and all temperature measurements made with a platinum and platinum-rhodium thermocouple. It took about 6 hours to heat the furnace from room temperature to the temperature of about 1280°C (2336°F) used during the testing. To prevent a strong overnight drop of the temperature, the furnace was switched to weaker current which kept the inside temperature around 700°C. Opening the furnace door for loading and removing of samples was always the cause of a rapid drop in temperature. It took several minutes to reach original temperature level and another several minutes to bloat the samples. To speed the testing and to insure more constant temperature within the fireplace the door was kept closed and the samples were placed and removed with a long metallic tongs through a small window cut in the door and closed with a removable firebrick plug. All bloating tests were made by N. Prokopovich with the assistance of Mr. David Johnson and Mr. John Koffski.

Small steel trays (2.25 x 1.75 x 0.5") of the type used by Cole and Zetterstrom (1954) were tried for placing the samples in the furnace. Experience showed, however, that the trays needed replacement after three to five runs. Round three inch diameter scorifying dishes available from the Denver Fire Clay Company proved successful. Violent "popping" of shale is common if the samples are placed directly in a hot furnace. Manz (1954 p. 12) used a preheating treatment to prevent the popping and according to Conley et al. (1948) such a preheat at 1000°F (538°C) does not reduce the bloating qualities of samples. Cole and Zetterstrom (1954) in their testing used a 10 minute preheat at 700°C (1293°F).

It should be pointed out that preheating takes place in commercial bloating kilns. Under industrial conditions, however, preheated material reaches the bloating zone without cooling while in laboratory testing cooling may occur between preheat and bloating.

A preliminary study of the problem during the present testing indicated that preheating may cause certain changes in bloating properties. A part of a sample of weathered Decorah shale from the Rochester area (52*) preheated at 800°C (1472°F) was bloated at three different temperatures in a room atmosphere and produced pellets with the following densities, i.e. grams per cubic centimeter.

at 950°C (1742°F) density of pellets over 1.6
at 1020°C (1868°F) density of pellets over 1.6
at 1050°C (1922°F) density of pellets about 1.6

* Throughout this report numbers of from 1 to 3 digits refer to the numbers of the samples as given in the tabulations and on Figures 2, 6, and 7.

Non-preheated half of the same samples under the same conditions produced pellets with the following densities:

at 950°C (1742 °F) density of pellets 1.7 to 1.2 (average 1.4)
at 1025°C (1877°F) density of pellets 1.4 to 1.1 (average 1.3)
at 1050°C (1922°F) density of pellets 1.2.

It was decided therefore not to use the preheating treatment to prevent "popping" during the main part of the testing. In order to keep the furnace clean of "popped" particles and to prevent individual samples from contamination all dishes were covered with thin sheets of asbestos paper.

Conley et al (1948) considered 5 to 15 min. time intervals as sufficient for bloating. Manz (1954 p. 13) used only 5 minutes in his experiments with North Dakota clays bloated at a constant temperature. According to Cole and Zetterstrom (1954 p. 21) "firing time in an electric furnace should be as short as possible. By having the furnace at the expected bloating temperature before a sample was charged, bloating could be completed in five minutes. When the temperature happened to be near the lower end of the bloating range for that material, a little more time was required." The bloating time used in a commercial kiln of Buildex Company, Ottawa, Kansas is 12 minutes. A seven minute bloating time was used during the main part of the present investigation.

A preliminary investigation before the present testing showed that great variations in the bloating temperature and bloating ranges could be caused by changes of furnace atmosphere or preheat. Dependence of bloating temperature on kiln atmosphere was well known after studies by Austin et al (1942). During the present study a change of furnace atmosphere from oxidizing to reducing was accomplished by blowing a stream of natural gas into the furnace. The change caused a definite decrease in the maximum bloating temperature. For example, part of a sample of weathered Decorah shale bloated at 105°C (1922°F) in room atmosphere produced particles with a density of 1.2, a second part of the same sample bloated at the same temperature but in a reducing atmosphere produced particles with a density of 0.7 to 0.8.

Surface color of the pellets bloated under reducing conditions was not the usual reddish-brown, but dark gray to black. Prominent changes of color of the interior parts of the pellets from reddish-brown to dark gray or black at the beginning of bloating in an electrical furnace in the usual room atmosphere were reported by Riley (1951). The same changes were typical during the present study. According to Riley the changes are caused by reduction of ferric iron into ferrous iron at high temperature. The reduction is accomplished by a liberation of oxygen, which is one of the major sources of gas phase during the bloating. Based on the Le Chatelier principle it is possible that a reducing atmosphere in the furnace or kiln can decrease the temperature of the reduction of iron and therefore can result in the liberation of oxygen and bloating at a lower temperature.

All tests listed in Table 9 used room atmosphere.

Taking into consideration the great variations of bloating temperatures and the difficulty of reproducing industrial conditions or correlations of laboratory and industrial bloating, it was decided for the preliminary work to limit the testing to bloating at maximal temperature without closer determination of bloating ranges. Hence the testing was reduced to an elimination of definitely non-bloating clays. According to Cole and Zetterstrom (1954 p. 20) "elimination of refractory samples is probably the most conclusive result of a series of electric furnace bloating tests, particularly when the firing is done quickly."

According to Cole and Zetterstrom, commercial bloating usually results between 1000° and 1200°C and the highest economically allowed temperature of bloating is not over 2400°F (or 1315°C). The U.S. Bureau of Mines Southeastern Experiment Station, Tuscaloosa, Alabama, considers as a bloating clay those that bloat at a temperature of 1320°C or less. According to Riley (1951) "Economic considerations usually limit kiln temperatures for commercially bloated aggregate to 2400°F or less." Manz (1954) referred to a temperature of 1800°-2200°F (1032-1204°C) as the most common bloating ranges of commercial kilns. The temperature in the bloating zone of the Buildex Company kiln at Ottawa, Kansas, is as high as 1950-2050°F (1115-1171°C).

The highest temperature used during the testing of Minnesota clays and shales by Riley in 1950 was 2300°F (1260°C) but 2400°F in 1951. The maximum temperature used in bloating tests by Cole and Zetterstrom was 1340°C (2444°F). Almost the same temperature of 2250°F (1282°C) was used by Manz (1954).

An average temperature of 1280°C (2336°F) was used during the testing described in this report. For a few special refractory samples the temperature was raised as high as 1300°C (2372°F), but no bloating resulted. All tests were made in the room atmosphere.

After the testing, most of the samples which showed bloating properties were definitely overbloated, hence their upper bloating limit in an electrical furnace in room atmosphere is lower than the testing temperature. Industrial bloating of the same samples in a kiln atmosphere would doubtless take place at a still lower temperature.

Description of tests.--All samples were briefly described after testing for degree of bloating, color, interior texture, and density. Interior texture and density depend greatly on the degree of bloating and are different in laboratory and industrial testing of the same samples. Density was determined by a float test in water. The size of cells which affect the density of pellets varies greatly within each sample. Cells in the central parts of a sample differ from the cells on the periphery. Most of interior parts of the bloated samples are dark gray or black and the outside parts range in their colors from dark gray and black to red-brown. The asbestos cover caused a change of color. The surface of the covered part of the samples was dark gray to black and the uncovered parts red-brown. This was particularly true for samples of the Decorah shale.

Reproducibility of experiments.--In order to check the reproducibility of experiments, fourteen samples were bloated twice. The reproducibility can be considered as fairly good, but showed slight differences in interior texture and color. Several refractory samples were tested a second time at temperatures up to 1300°C but do not bloat.

MINERALOGICAL AND CHEMICAL COMPOSITION OF SHALE AND CLAYS

The relationship between chemical and mineralogical composition of clays and their bloating properties has been frequently discussed in the literature, but problems remain. According to Cole and Zetterstrom and to Manz bloating properties are not related to the main mineralogical constituents of clays but depend on extraneous materials usually referred to as impurities. No relationship between mineralogical compositions and bloating properties was detected by Riley for two pairs of bloating and non-bloating samples of Decorah shale from southeastern Minnesota. Further broad studies of the subject brought Riley (1951) to the following conclusions: Bloating shales and clays must have a proper chemical composition to insure a development of a viscose, high temperature, glassy phase and to liberate a sufficient amount of gases at the temperature of formation of the glassy phase. The composition diagram of two major oxides--SiO_2 and Al_2O_3 and total fluxing agents shows a definite "area of bloating" (Fig. I). Within this field raw materials have the desirable composition which insure the development of viscose high temperature glassy phase. To use the diagram, chemical analyses of clays or shales should be recalculated so that the sum of SiO_2, Al_2O_3, CaO, MgO, FeO, F_2O_3, and $(K, Na)_2O$ is equal to 100% and the percentages obtained plotted on the diagram. Several experimental improvements of non-bloating clays by adding corresponding oxides proved that the basic principles of the diagram are correct (Riley 1951). The diagram, however, does not give information about the second requirements of bloating clays--the liberation of gas phases. According to Riley among all accessory minerals of the Decorah shale, hematite, pyrite, and dolomite are the only minerals which could dissociate and produce gas phase at the proper temperature. Cole and Zetterstrom and Manz listed carbonaceous materials, iron compounds, limestone, dolomite and gypsum as potential sources of gas phase.

Because the chemical composition of a sediment is mainly a reflection of its mineralogical composition, the mineralogy of clays is important for bloating. This statement, however, does not mean that the presence or absence of certain "critical" minerals may be a cause of bloating. The importance is not only the type of minerals present in a clay, but also their quantity. Chemical and mineralogical data on Minnesota clays is incomplete. Several chemical analyses of different clays are reported by Grout and Soper (1914). Six more complete and recent analyses of Decorah shale and Glacial Lake clays reported by Riley (1950) and Bradley (1949) are given in Table 2. Numerous partial chemical analyses of samples of the Decorah shale which were bloated during the present study were previously reported by Prokopovich and Schwartz (1956).

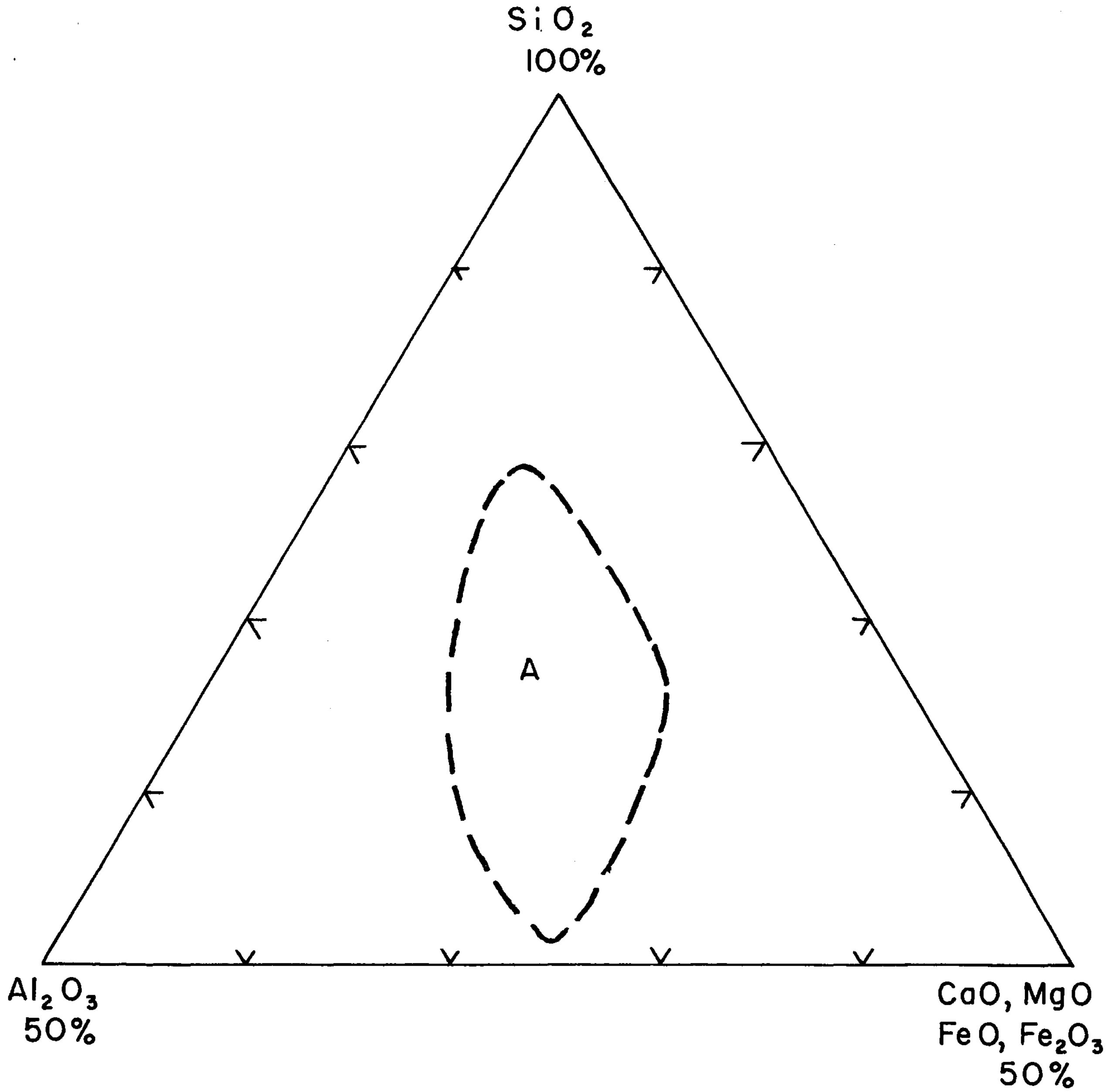


Figure 1. Composition diagram of major oxides showing "area of bloating" (A).

TABLE NO. 2. Chemical Analyses of Decorah Shale and Glacial Lake Clays.

	69°	69d**	25c**	25b°	165°	166°
SiO_2	40.35	48.94	48.50	43.10	50.84	51.95
Al_2O_3	16.62	20.33	20.78	15.16	13.43	10.54
Fe_2O_3	4.85	4.97	3.75	3.59	4.85	2.26
FeO	.55	.71	1.50	1.22	.93	1.28
MgO	1.95	2.53	2.83	2.84	4.68	4.84
CaO	12.19	2.89	2.26	10.68	7.30	10.29
Na_2O	.12	.20	.12	.12	1.03	1.37
K_2O	6.63	7.64	7.69	6.66	2.50	1.86
H_2O+	4.18	5.16	4.97	3.37	3.71	2.40
H_2O-	2.59	3.33	4.06	2.50	2.70	1.28
CO_2	8.96	2.25	2.05	8.95	6.86	10.87
TiO_2	.59	.78	.79	.60	.66	.49
P_2O_5	.32	.31	.20	.40	.13	.13
SO_3	-	-	.07	.14	-	-
S	.04	.02	.81	.94	.02	.16
MnO	.10	.04	.03	.07	.09	.08
BaO	.01	.01	.01	.00	.03	.05
less 0 for S	.02	.01	.41	.47	.01	.08
Total	100.03	100.10	99.91	99.87	99.75	99.79

Rock Analysis Laboratory, University of Minnesota, Eileen K. Oslund, Analyst.

**) Bloating.
°) Non-bloating.

TABLE NO. 3. Partial Chemical Analyses of Decorah Shale from Summary Report #8, Minnesota Geological Survey

Location Numbers refer to Table 6.

Location	Formation	CaO	MgO	CO_2	Insol-ble	Fe_2O_3	FeO	Al_2O_3
1	Decorah shale	9.59	1.62	5.82	58.14	5.68	0.19	16.62
3	" " middle	1.96	2.39	1.04	67.38	4.72	0.61	20.46
6a	" " upper	2.45	2.28	1.22	70.74	4.72	0.59	20.37
6b	" " lower	4.06	1.82	3.04	71.42	4.70	0.52	14.98
9b	" " lower	0.95	1.78	0.38	77.23	5.32	0.49	13.24
10b	" " upper	16.84	1.69	12.62	49.25	4.00	0.54	17.09
11a	" " upper	1.20	1.93	0.38	68.15	5.38	0.44	20.04
11b	" " lower	1.99	1.62	1.14	74.22	4.83	0.41	21.17
13a	" " upper	1.57	1.76	0.80	68.99	5.08	0.60	23.70
14	" "	2.48	1.50	1.68	72.16	6.15	0.46	21.47
15	" "	1.59	1.62	0.28	72.52	5.93	0.64	20.32
16	" " upper	3.02	2.25	1.92	61.35	5.71	0.65	22.96
20	" " upper	0.66	2.12	0.40	68.48	4.96	0.81	22.10
21a	" " upper	7.03	2.10	2.80	61.40	4.63	0.78	22.19
21b	" " middle	3.35	2.03	2.68	65.34	4.16	0.81	22.92
23	" " upper	4.47	1.64	2.04	68.77	6.49	0.40	21.11
24	" "	1.65	1.28	0.59	76.34	7.24	0.51	19.47
25a	" " upper	10.18	1.83	7.62	53.28	4.78	0.83	22.86
25b	" " middle	1.28	1.96	0.34	67.52	6.09	0.73	17.67
34a	" "	1.98	2.50	1.23	65.97	5.41	0.72	21.26
36a	" "	0.51	2.57	0.14	67.31	5.39	0.63	20.87
37	" " lower	0.73	2.54	0.16	65.47	5.66	0.78	23.36
43b	" " middle	1.75	2.64	0.58	63.84	5.88	0.70	24.09
45a	" " upper	4.10	2.56	2.44	63.14	5.52	0.82	22.60
45b	" " lower	0.75	2.45	0.16	72.05	4.89	0.77	23.60
46	" "	0.71	2.72	0.56	71.10	4.80	0.74	22.10
50b	" " lower	0.68	2.51	0.32	70.06	5.32	0.59	22.89
55a	" " upper	5.56	2.46	3.58	64.00	4.83	0.61	21.44
55d	" " lower	2.24	2.69	1.32	65.29	5.73	0.63	22.84
62a	" " upper	21.64	2.33	19.26	48.53	2.65	0.51	10.91
69a	" " upper	0.51	2.35	0.34	68.55	6.22	0.82	20.00
73b	" "	4.34	2.45	3.48	67.60	3.10	0.93	18.74
74a	" " upper	5.03	2.53	3.96	65.02	3.60	0.82	17.55
80a	" " upper	1.44	2.55	0.62	67.65	5.41	0.72	23.35
80b	" " middle	0.07	1.91	0.15	76.09	4.16	0.60	20.47
80c	" " lower	0.32	1.95	0.40	76.10	4.03	0.61	17.33
81a	" " upper	0.29	2.16	0.06	73.92	4.89	0.56	22.08
81c	" " lower	1.11	2.01	0.70	73.32	5.76	0.70	21.39
82	" " upper	14.68	1.96	10.42	48.04	6.91	0.61	14.40

The analytic work was performed in the chemical laboratory of the Mines Experiment Station of the University of Minnesota and showed rather low amounts of MgO in the shale. The mineralogical composition of the Decorah and Glenwood shale was studied by Gruner and Thiel (1937) who reported authigenic feldspar in the shales. The presence of feldspar is the reason for the relatively high potassium content of the shale. Illite, orthoclase, and some pyrite were detected in clay fractions of the Decorah shale by Riley. Alkaline earths (CaO, MgO) and alkalies (K_2O, Na_2O) act as fluxes thus feldspar has a fluxing effect owing to the presence of alkalies.

Drift clays have a variable mineralogical composition. In general gray drift deposited by the Keewatin ice is rather calcareous and drift of the Lake Superior ice lobe is poor in carbonate and rich in silica (as sand). An exception is red Valders drift which is highly calcareous. The chemical composition of drift greatly affects the composition of corresponding glacial lake deposits which were developed by re-working of corresponding kinds of drift. No definite clay minerals could be detected in several samples of glacial lake clays near Duluth by Bradley. X-ray study of fine fractions of the clays indicated only quartz, calcite and dolomite. Montmorillonite was identified by Manz (1954) as the main clay mineral of Glacial Lake Agassiz clays and silts in North Dakota, at the Minnesota State line.

Cretaceous shales also show differences in chemical composition, and some are high in alumina. Thermo-differential analyses of several high alumina clays made by N. Prokopovich produce a bauxite pattern. Other probable Cretaceous clays scattered over southeastern parts of the state were determined by thermo-differential analysis to consist principally of kaolinite. Both bauxitic and pure kaolinite clays are non-bloating. Halloysite was reported by Bradley (1949) as the main mineral in the bloating Cretaceous clays in the old Och's clay pit near Springfield. The same author named kaolinite as the main clay mineral of residual Precambrian non-bloating clays from location 138.

STRATIGRAPHY OF MINNESOTA

Clays and shales occur in Minnesota in several rock formations of different areal extent. A list of the rock formations for the samples and a summary on their age, composition, and thickness are given in Table 3.

TABLE 4

Generalized Column of Rock Formations
Cambrian to Recent

Age and name of formation	Thickness in feet	Main rock types
CENOZOIC ERA		
QUARTERNARY		
Recent deposits	0-200	River alluvium, lacustrine sand, clay, silt, marl, peat
Pleistocene (= Glacial epoch)	0-500+	Glacial tills, glacial lake, clay and silt, loess, etc.
Wisconsin glaciation		
Valders substage		Valders till, glacial lake deposits
Two Creeks interstadial		Glacial lake deposits
Mankato substage		Superior, Keewatin and Patrician tills, glacial lake deposits
Interstadial		Glacial lake deposits, dunesand, etc.
Cary substage		Keewatin, Labradorian and Patrician tills, glacial lake deposits, dunesand
Interstadial		Loess and fossil soil
Tazewell substage		Probably missing in Minnesota
Interstadial		Loess and fossil soil
Iowan substage		Thin Keewatin till
Sangamon interglacial		Loess and fossil soils
Illinoian glaciation		Labradorian and Patrician tills
Yarmouth interglacial		Fossil forest bed
Kansan glaciation		Weathered Keewatin till, mostly buried
Aftonian interglacial		Fossil soil
Nebraskan glaciation		Small patches of Keewatin till
MESOZOIC ERA		
CRETACEOUS		
Coleraine Formation	70±	Sandy shale, iron ore, sandstone (Known along the Mesabi range)
Big Cottonwood	70±	Shale, sandstone, lignite
Ostrander	50±	Gravel, sand, sandstone, conglomerate, ore

Age and name of formation	Thickness in feet	Main rock types
PALEOZOIC ERA		
DEVONIAN		
Cedar Valley	100	Dolomite, limestone, argillaceous dolomite
ORDOVICIAN		
Maquoketa	100-150	Buff shale dolomite, interbedding of shale and limestone
Galena	150±	
Stewartville member		Buff Dolomite
Prosser member		White to gray limestone, Dolomite, shaly limestone
Decorah	75-35	Greenish gray shale with thin limestone lenses and beds
Platteville	30	Gray to buff dolomite
Glenwood	20±	Thin shale zone (5 ft. ±) over sandstone
St. Peter	100-200	White sandstone, silty sandstone
Shakopee	75	Buff to gray dolomite
Root Valley	15	White to brown sandstone
Oneota	60-200	Buff to gray dolomite
CAMBRIAN		
Jordan	60-200	White to buff sandstone
St. Lawrence	130	Buff sandy dolomite
Franconia	100	Green siltstone and sandstone
Dresbach	450	Sandstone, shaly sandstone
PRECAMBRIAN		

The part of the table dealing with the glacial epoch needs some explanation: During this time Minnesota was invaded several times by ice masses which were developed in three centers of glaciation known as Labradorian, Keewatin, and Patrician and the glaciers moved outward from these centers. The exact age and space relations between ice sheets are sometimes uncertain, but, glacial till deposited by different glaciers differs greatly because of the composition of the bedrock overridden by the ice.

Keewatin ice (Des Moines Lobe, Grantsburg and St. Louis sublobes) passed over an area rich in limestone and shale southwest of Hudson Bay. Glacial till or drift accumulated by this ice is gray to dark bluish-gray in color, highly calcareous and rich in limestone pebbles and cobbles. The distribution is shown on Figure 2. This so-called "gray drift" is usually clayey but contains sandy and pebbly layers and pockets. The uppermost 20 to 30 feet of gray till are commonly oxidized, leached and bleached to a buff color due to the surface weathering in the post-glacial time. Similar weathered zones were reported at a depth in numerous water wells. Such buried zones of bleaching are due to an ancient weathering in interglacial periods. The bloating properties of weathered and fresh drift should be different, but no representative samples were available during the present investigation.

Patrician and Labradorian (Superior Lobe) ice masses passed over areas rich in red colored late Precambrian sandstone and shale. Drift deposits of both ice masses are red to brown colored, stone and sandy rather than clayey. This so-called "red drift" differs from late Wisconsin till which is known as Valders till and is red, clayey and calcareous.

The surface distribution of different types of drift is well shown on the maps of surface formations of the State of Minnesota (Leverett and Sardeson 1932). More detailed information on subsoil conditions can be obtained from soil maps of different counties, which are available at the University of Minnesota Department of Soils and at the Soil Conservation Service, Federal Counrts Building, St. Paul 2, Minnesota.

Distribution of bedrock formations is shown on the Geologic Map of the State (Grout 1932). The active and abandoned clay pits are shown on the map of mineral resources compiled by Schwartz and Prokopovich (1956). The distribution of samples utilized in this report is shown on Figure 3.

BLOATING PROPERTIES OF DIFFERENT TYPES OF CLAYS

General -- Geographical distribution of the formations listed above permits an outline of several types of occurence of clay which are shown on Fig. 2. They are as follows:

- Paleozoic bedrock
- Kansan gray drift and loess
- Wisconsin gray drift
- Wisconsin red drift
- Valders drift

FIGURE 2

MAP SHOWING THE DISTRIBUTION OF THE MAJOR CLAY PROVINCES OF MINNESOTA

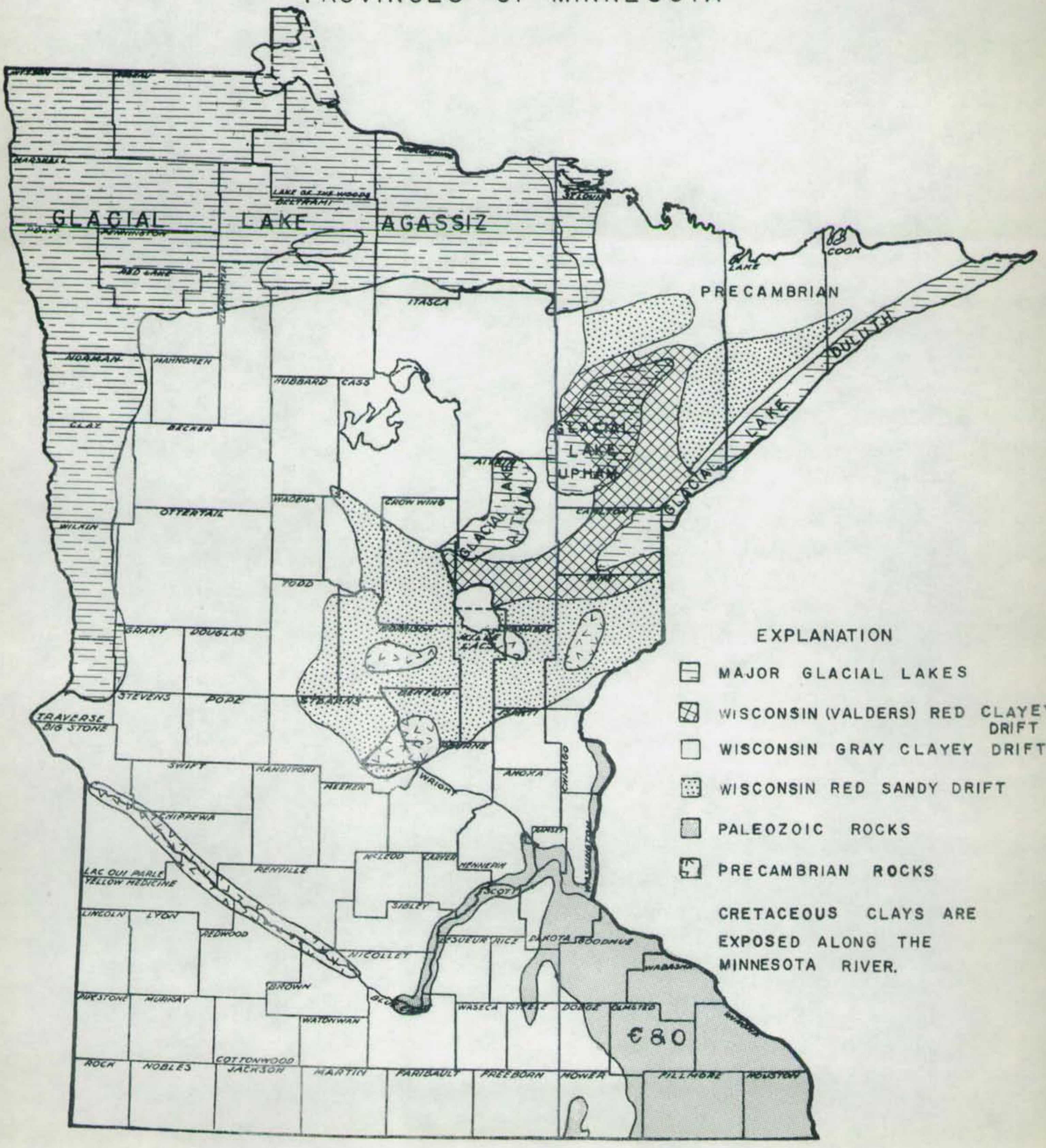
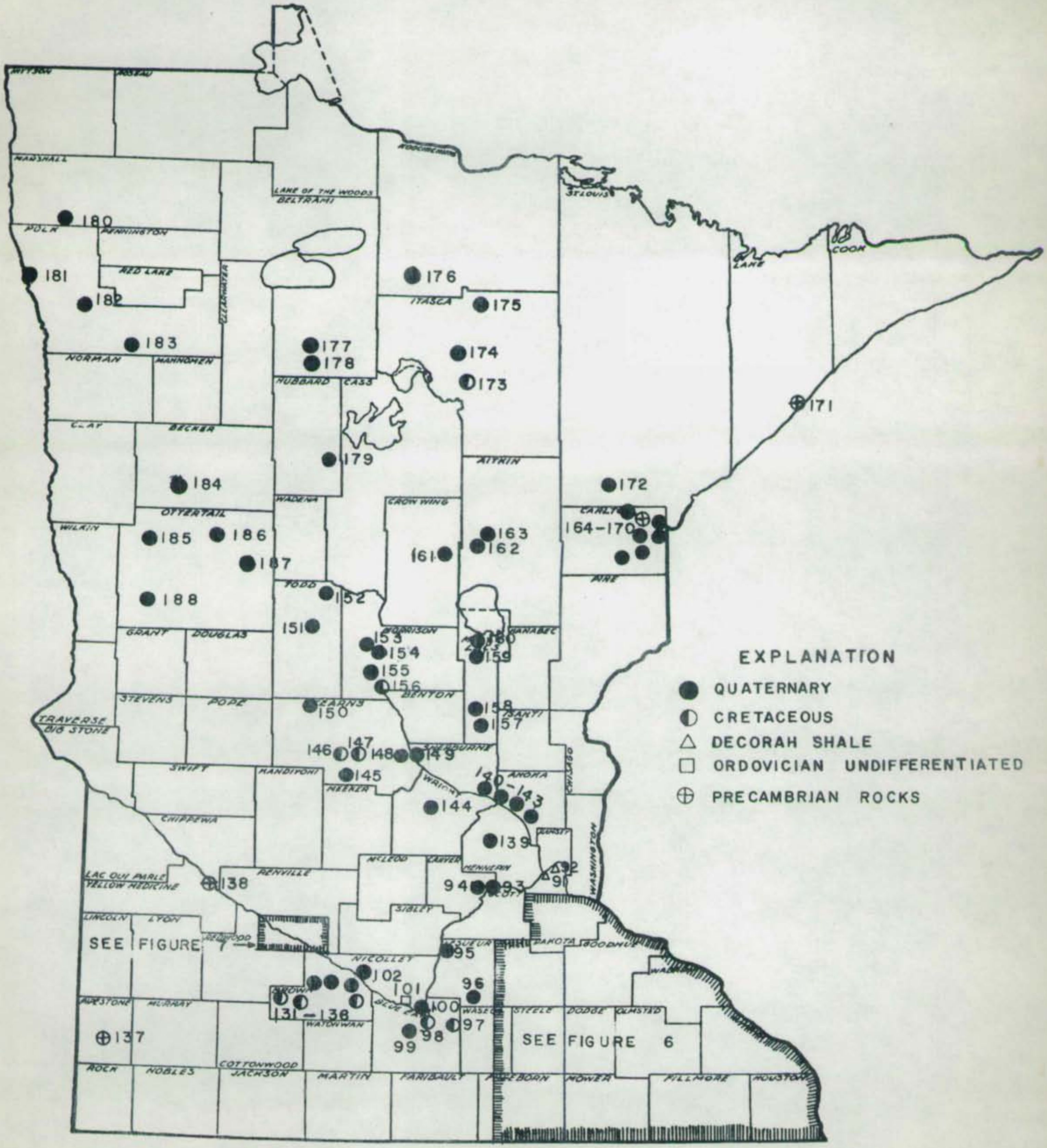


FIGURE 3

MAP SHOWING LOCATION OF SAMPLES TESTED



Glacial lake deposits
Precambrian bedrock
Residual Precambrian clays
Cretaceous clays
Miscellaneous clays

Paleozoic bedrock --Paleozoic rocks occur in the southeastern part of the state. (Fig. 2).

The main, and probably the only industrially important clay-bearing unit in the area, is the Decorah shale. The shale crops out as an irregular belt from the southeastern corner of Fillmore County to the northwestern corner of Goodhue County (Fig. 4). Eastward and northward from that belt the shale is completely eroded with the exception of a few isolated deposits. The most important group of such deposits occurs at St. Paul and is excavated by the Twin City Brick Company. Another similar deposit of unknown thickness occurs in the central part of Dakota County. Westward of the belt of outcrop the shale becomes rapidly deeply buried under younger formations, mainly limestone. Underlying the shale is the Platteville dolomite. Because of the resistance to erosion of limestone and dolomite the outcrop area of the shale usually appears as a narrow terrace which follows the main plateau slope. The full thickness of the shale is present only at the limestone capping.

Shale also occurs as isolated or half isolated erosional remnants of the plateau (Fig. 5). Thick limestone overburden is absent or strongly reduced in thickness, deposits are small. Exposed parts of such deposits are composed of deeply weathered shale which seems to bloat better than fresh shale. The degree of weathering, however, decreases with depth and the deposit may be of different quality at different points.

Typical Decorah shale is dark greenish gray, but brownish gray toward the bottom and breaks into blocky lumps. The shale contain numerous thin (5 x 4") layers, lenses and nodules of limestone which at high temperature produce lime. A separation of limestone will be necessary in using the shale for bloating. The thickness of the shale decreases toward the southeast, for example, in Section 12:101-17, Houston County it is only 23 feet thick; at Fountain and vicinity in Fillmore County 36-37 ft., at Cummingsville, Olmsted County 46 ft., at Cannon Fall, Goodhue County about 60 ft. An especially thick section of shale was observed during the present study in the western part of Goodhue County.

According to Riley (1950) several deposits of the Decorah shale in and near the Twin Cities are of a bloating type and have a favorable long bloating range. During the present investigation numerous samples of the shale were tested and most of them were of the bloating type (1, 3, 6-11, 13-17, 19-25, 33?, 34-41, 43-46, 50-53, 61-64, 69-71, 73, 74, 78-85, 88, 90-92). Only relatively few samples did not bloat (7, 55, 61?, 69, 71-74, 83, 85). See Figure 6. The shale can be considered as a good source of bloating clays.

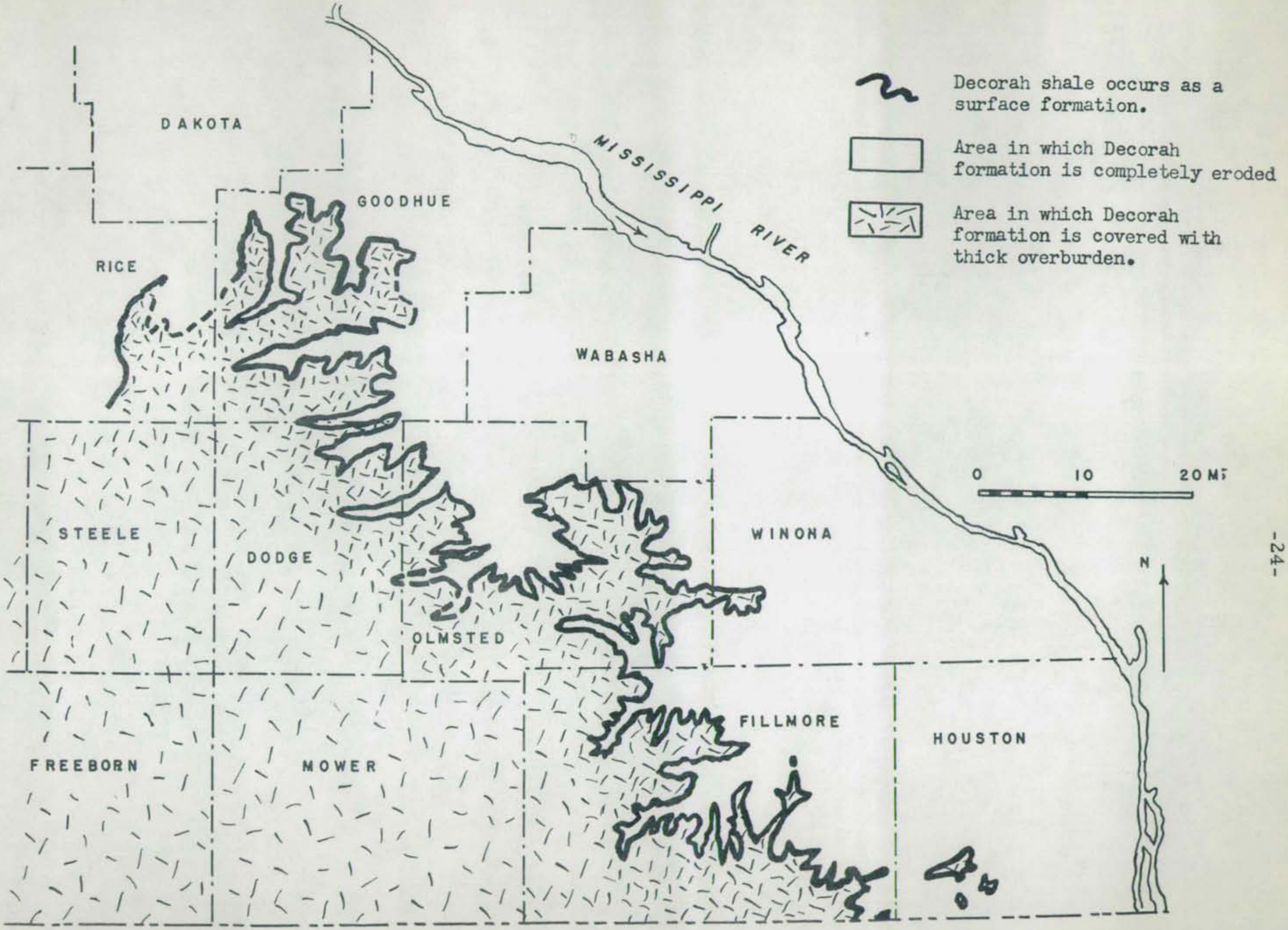


Figure 4 - Distribution of Decorah formation in southeastern Minnesota.

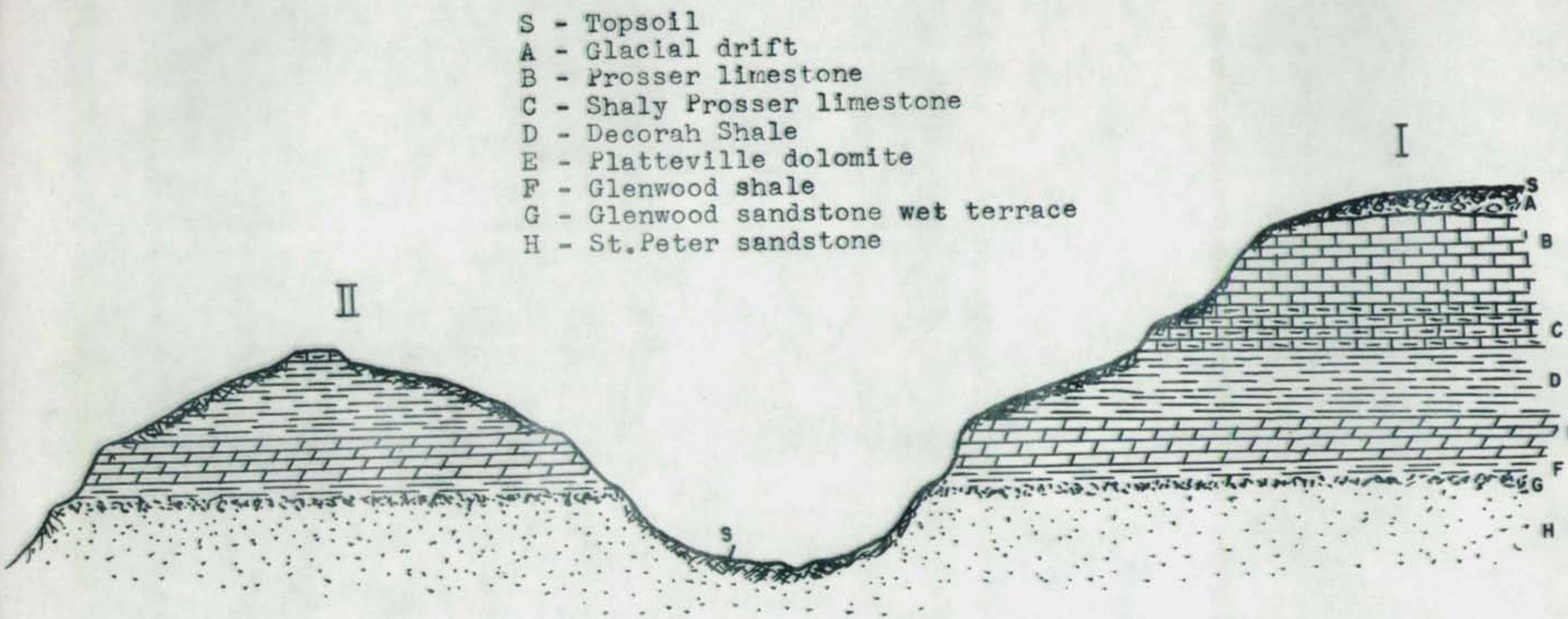


Fig. 5.
Two types of occurrence of Decorah shale in southern Minnesota
I Shale deposits on the main plateau.
II Shale deposits in an erosional remnant.

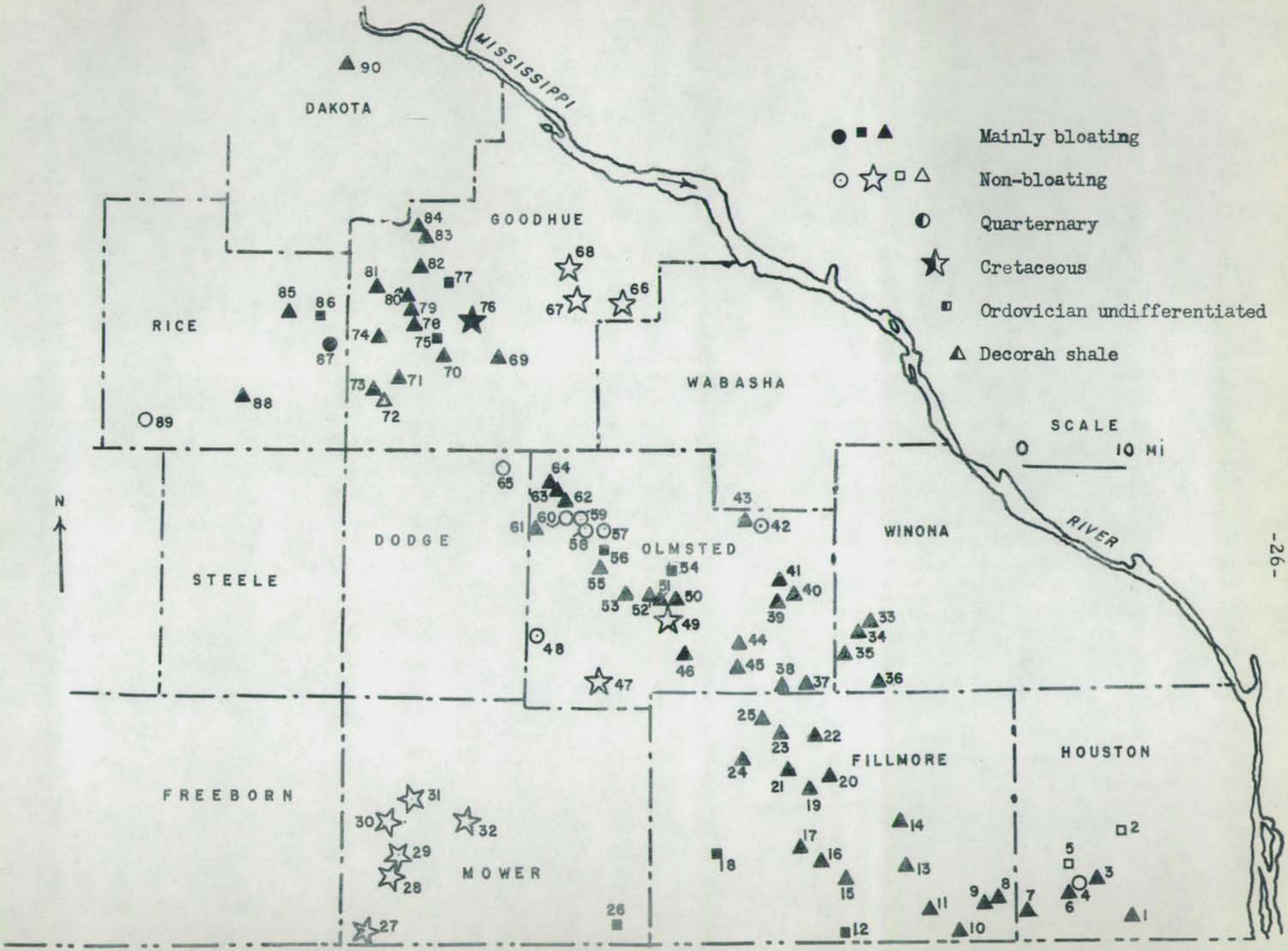


Figure 6—Map of southeastern Minnesota showing locations of samples.

A thin shale usually called the Glenwood beds occupies a position between the Platteville limestone and the St. Peter sandstone. Several samples were tested and all bloated (9, 35, 36, 54, 56, 86). This shale however, does not have any commercial importance because it is commonly only 3 to 4 feet thick. An unusually thick section of the shale, was observed (over 10 feet) at location 86 in Rice County.

One or two shaly layers 1 to 3" thick are present at the top of Platteville dolomite. The shale is usually known as "putty layers" and is composed of bentonite. Several samples collected at locations 6, 35, 38, 50, and 84 bloated. Samples of the same beds from locations 61, 62, and 84 did not bloat. More detailed study of these samples may give theoretically important information on bloating but they lack commercial importance. Three samples of "oil shale"--a dark brownish highly calcareous shaly rock, which occurs at places in the upper part of the Platteville formation did not bloat (50, 61, and 84).

Not much information was obtained on the bloating properties of shale from the Maquoketa formation because of its poor exposure. The formation is composed of interbedded shale and limestone and two samples bloated.

Two samples of thin shaly layers from the Shakopee dolomite (2, 5) tested during the study did not bloat, but samples of thin shaly layers from Prosser limestone (75, 77) and from the Cedar Valley formation bloated.

A relatively small area of Paleozoic bedrock close to the surface extends along the Minnesota River Valley (Fig. 6). In this area Decorah and Glenwood Shales are completely eroded and the only shale-bearing formation in the so-called Blue Earth siltstone, which sporadically occurs between Jordan sandstone and Oneota dolomite. The formation is not of industrial importance because of its thinness and sporadical occurrence. The few samples of Blue Earth siltstone tested (101) were non-bloating.

Kansan gray drift and loess -- In most parts of the state Kansan gray drift is buried under a thick overburden of Wisconsin gray drift and is only sporadically exposed in some deep road cuts and valleys. As a surface formation Kansan drift occurs only in the southeastern and the extreme southwestern corners of the state which were not covered by the last Wisconsin glaciation but in a part of these areas the drift is covered with a blanket of loess. The Kansan gray drift is clayey and calcareous. A few samples of the drift from the southeastern part of the state which were tested during the study did not bloat (48, 59, 60) an exception is No. 87 from Rice County. Two of three stations along the Minnesota River Valley (95 and 100C) also have non-bloating Kansan drift, but the sample from the third (102) seems to be of a bloating type. One sample of Kansan gray drift from the central part of the state (161d) was of a non-bloating type. In general, Kansan drift seems to be rather unfavorable for bloating purposes.

Loess covered areas are geographically closely related to the areas covered with Kansan drift. According to Riley (1950) some loess deposits in Olmsted County have satisfactory bloating properties. Present testing of the same samples, however, gave negative results. A few additional loess samples also did not bloat (42, 57, 65) but an exception is No. 58. The exact nature of all samples is uncertain. Some of the samples are doubtless loess but others were partially reworked. The difference between present results and Riley's data was probably caused by different methods of bloating. In general, loess seem to be unfavorable for industrial bloating.

Drift clays older than Kansan are mostly not exposed and therefore are of no commercial value. Only one sample of possibly Nebraskan gray drift (161E) was tested and it bloated.

Wisconsin gray drift-- Over half of the surface of the state of Minnesota is covered by gray, calcareous till deposited by the Wisconsin glaciation (Fig. 2). At places the till is reworked and deposited in glacial lakes. Gray till is pebbly or bouldery and contains irregular pockets and lenses of sand and gravel. Several samples of gray drift tested by the Mines Experiments Station of the University of Minnesota bloated. Numerous samples of the drift tested during the present investigation also bloated (94, 100, 134, 143, 152, 154, 160, 174, 175, 184, 186); others, however, did not bloat (100, 133, 144, 145, 151, 174, 185, 187, 188) or their bloating properties were uncertain, for example numbers 176, 185. (See Fig. 3 for locations).

The use of drift clay for commercial bloating is hindered by the presence of mechanical non-bloating impurities such as sand, gravel, and boulders. Many pebbles in the drift are composed of limestone which produce lime. In the past the presence of pebbles, particularly limestone pebbles, prevented the use of drift clays in the brick industry (Grout and Soper 1914). In general, gray drift probably cannot be recommended for a big scale bloating industry, unless a cheap and effective method can be devised for the separation of pebbles.

Wisconsin red drift-- Wisconsin red drift is exposed as a surface formation in the east-central part of the state and in its extreme northeastern corner (Fig. 2). The typical drift is too sandy and too pebbly to be considered as a clay-bearing formation. More clayey facies of the drift, particularly drift reworked by former glacial lakes, are less stony. Most of the samples of the drift which were tested during the present investigation were of a non-bloating type (155, 158, 159, 160) and only two localities (161 and 170) seemed to have bloating properties. In the past red drift was excavated at a few places for manufacturing brick, but was found too sandy and pebbly for this purpose. Much better results were obtained with red laminated clays (Grout and Soper 1914).

Valders drift-- This drift was first recognized in the state of Minnesota by Dr. H. E. Wright, Jr. It is "red" in color, but clayey and calcareous, and therefore can be easily distinguished from the typical sandy non-calcareous Wisconsin drift. Valders drift was deposited by the Superior lobe of the very last advance of the Wisconsin ice sheet. It occupies only a two to five mile wide zone along the North Shore of Lake Superior. At the head of the lake the main lobe developed two sublobes, one extended toward the Cuyuna district and the other toward the Mesabi district (Fig. 6). The drift appears as a thin non-continuous veneer over older tills, but may be thicker in some valleys. The only sample of the Valders drift studied during the present testing seemed to be of a non-bloating type (172).

Glacial lake deposits--During the melting of Pleistocene glaciers large amounts of water accumulated in numerous "glacial lakes," most of which disappeared after the final retreat of the ice. The largest glacial lakes were Lake Agassiz, Lake Aitkin, Lake Upham, and Lake Duluth (Fig. 2).

The typical sediment of glacial lakes is a laminated clay--an interbedding of clayey and silty layers which was produced by seasonal changes in sedimentation. Laminated clay is a reworked glacial till and the action of glacial lakes can be considered as a big-scale "natural screening" of till from pebbles and boulders. Many lake clays have been successfully used in the past for manufacturing bricks.

Several samples of glacial-lake clays were tested during the present investigation. Eight of these samples came from the area covered by the Lake Agassiz (#180-183). Lake clays collected at Grand Forks (181) bloat but apparently similar clays at Warren (#180) do not bloat. The nature and bloating properties of clays collected at Crookston and Fertile (#182, 183) are uncertain. Taking into consideration data obtained by Manz (1954) in North Dakota near the Minnesota line the Lake Agassiz clays should furnish some clay suitable for bloating. According to Manz the typical clay beds of Lake Agassiz are 40 to 75 ft. thick and are composed of non-stratified gray to greenish-gray plastic montmorillonitic non-calcareous clay which contains organic material. Clay beds are covered with 20 to 35 ft. of yellow calcareous silt. About 50 ft. of plastic clays under 20 ft. of silt are reported by Manz to be present at Crookston, Minnesota. All Lake Agassiz clays bloat within the temperatures from 1850 to 2100°F.

Testing of samples from two locations (#162 and 163) which represent sediments of glacial Lake Aitkin gave uncertain results. Part of the samples bloated, but others did not bloat. The same is true for several samples representing glacial Lake Duluth (164-168). Deposits of glacial lake clays in Anoka and Carver Counties furnished some bloating clays (140-142 and 93), but other lake clays which originated from gray drift are of a non-bloating type (Stations #94b, 94, 177, 179, 187).

In general, glacial lake clays seem to be one of the most promising sources of clay for bloating industry. They are sufficiently thick, large, and free from mechanical admixtures of gravel and pebbles. Variations of bloating properties of these clays, however, make necessary a special investigation for each deposit.

Precambrian Rocks--Most Precambrian igneous and metamorphic rocks are not suitable for bloating. Riley (1951) stated that such rocks as rhyolite, trachyte, whose chemical composition corresponds to the "bloating area" shown in Figure 1, bloat when ground or cast into briquets. The feasibility of such a process is doubtful.

The Virginia slate is, in reality, an argillite. Samples from the banks of some of the iron ore pits were tested by the Mines Experiment Station, University of Minnesota and found to bloat.

A sample of Keweenawan red shale from Fond du Lac was tested but failed to bloat. At a few places, particularly along the Minnesota River Valley, Precambrian granites and to a lesser extent, other rocks have been deeply weathered and then preserved under deposits of Cretaceous sediments. None of these clays bloated (103-130, 138, 147).

Cretaceous clays--Shale, sandstone, and other sediments of Cretaceous age occur as a discontinuous series of deposits in the western and southern parts of the state but are mostly buried under from 100 to 500 feet of drift. At a few places, particularly along the Minnesota River Valley, the drift is lacking or thin and Cretaceous clays are accessible. Most of these clays are non-bloating but the clays at Springfield and New Ulm bloat satisfactorily (132, 135, 136). At Richmond in Stearns County (146 and 147) the younger beds of Cretaceous shale have traces of lignite and show good bloating properties. An isolated patch of bloating Cretaceous clay is present in Itasca County (173). Scattered samples from many other areas were all non-bloating (27-32, 47, 49, 66-68, 98).

Miscellaneous clays--A few calcareous clays from river and lake beds were tested (131, 139, 159, 161, 163) and found to bloat. Whether such deposits would be uniform and of sufficient size to supply a plant is doubtful.

TABULATION OF BLOATING TESTS

For convenience the results of the tests are tabulated grouped by counties. In this arrangement clays of unlike properties may occur adjacent in the tables.

As previously noted the clays were bloated at maximum temperatures up to 1300°C. An average temperature during bloating was about 1280°C. The time of bloating was held as closely as possible to seven minutes.

The place where the clays were collected are shown by numbers on Figures 2, 6, and 7. Figure 2 also shows the distribution of the clay-bearing provinces within the state. If more than one sample was collected from the same outcrop or vicinity the samples are described under the same number but are lettered a, b, c, etc., and a corresponding explanation is added in the third column. The letters, however, are omitted on the maps. Starlets after the number of a station indicate that all or some of clay samples from this station were studied petrographically by Mr. E. Bradley.

The second column describes the location of the samples by townships, range, and quarter-section but some of the samples collected during earlier investigations have only a descriptive location -- for example, "Southeast of St. Cloud, West of State Highway #152."

Locations are abbreviated as follows: from "Northeast quarter of Section 21, township III North, Range 18 West" to NE 1/4 21:111-18 and from "at eastern quarter corner Sec. 21, township 111 north, range 18 west" to E 1/4 cor. 21: 111-18. Several other abbreviations used in this and other parts of the tabulation

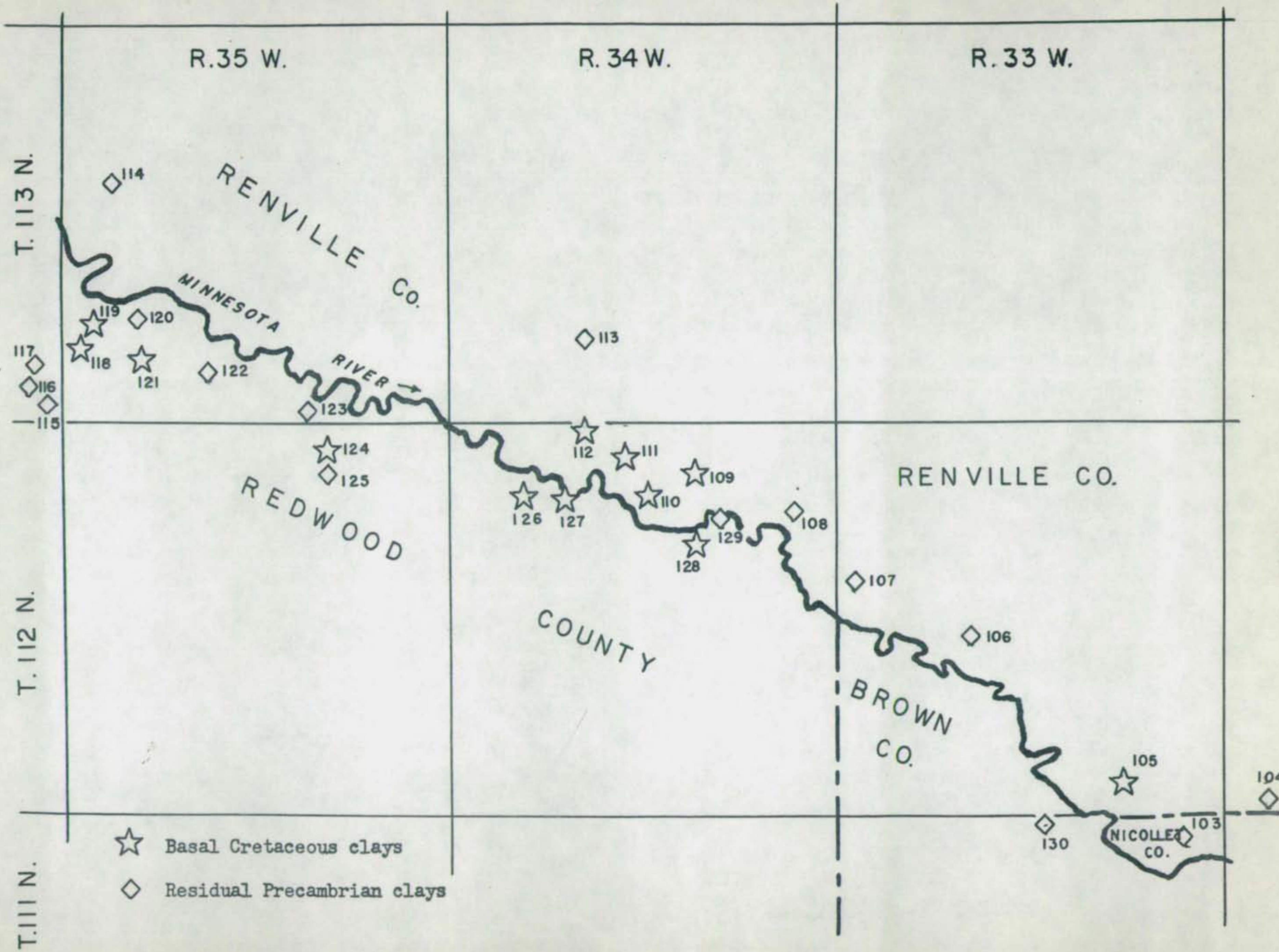


Figure 7 -Location map of the samples along the Minnesota River.

are explained in table 5.

The third column includes information about the types of sample and/or exposures sampled.

The fourth vertical column indicated the person who collected the sample. The following abbreviations are used in this column:

Letter "B" indicates samples collected by Kenneth F. Bickford

Letter "E" indicates samples collected by Edward Bradley

Letter "M" indicates miscellaneous samples in the collection of the Minnesota Geol. Survey.

Letter "P" indicates samples collected by Nikola P. Prokopovich

Letter "R" indicates samples collected by Charles M. Riley

The fifth column reports the formations to which the sample belongs. Some abbreviations used in this column are explained in table 5. The word Residium is used in the column to refer to residual clays over Paleozoic beds. Residual clays developed by weathering of Precambrian crystalline rocks are indicated as "pGw," and more or less unweathered Precambrian rocks as "pC". The upper part of some Precambrian residual clays has been reworked during Cretaceous time at many places. Cretaceous age, however, is applied only in a few cases where such reworking was typical. Numerous isolated clay bodies scattered throughout the southeastern part of the state do not contain fossils so their age is doubtful, but a Cretaceous age is commonly suggested. In such cases a question mark is added to the word Cretaceous. An attempt was made to divide the Quarternary deposits according to their age and lithology into Wisconsin and Kansan drifts, glacial lake deposits, loess and so on. The term Quarternary is used only for a few samples for which a more accurate designation was impossible. On figures 3, 5, and 6 samples collected from different formations or group of formations are shown by different symbols. If several formations were sampled in the same vicinity the symbol used for the stations represents the main clay bearing unit.

The sixth column gives a brief description of the samples before bloating. Numerous abbreviations used in the column are explained in Table 6. Color determinations were made according to the "Rock color chart". Small starlets at the end of the statements indicate partially chemically analyzed samples. Their analyses are reported in Table 2 of Summary Report No. 8.

The seventh column indicates the reaction of small fragments with hydrochloric acid before bloating. Effervesence is given as positive, strong, and very strong and indicates the presence of calicum (and/or magnesium) carbonates. If the reaction reported in the column was observed only in a part of the sample and was absent in other parts--the results are written in brackets.

The eighth column reports the surface color of the pellets after the bloating according to the color chart. The value of these colors, however, is questionable. They depend greatly on the reduction and oxidation potential in the kiln. Colors developed in an electric furnace are different from colors formed in a commercial kiln.

The same is true for the type of interior texture which is reported on the ninth column. More important is the abundance of lime, which has a tendency to destroy the bloated pellets on exposure to moisture. The size of "sponge-like" cellular texture developed during the bloating varies in the exterior and interior parts of the same sample and only an average value is reported in the table.

The tenth column indicates an average density of the samples after bloating. The symbol "1+" indicates samples with a density of over one--i.e. heavier than water. The symbol "1-"--the samples with a density below one, and $1^{\pm}$ the samples with a density equal to the density of water.

The eleventh column in the tables represents the "degree of bloating" after a 7 minute heating at the maximum bloating temperature (about 1280°C). The exact determination of the "degree of bloating" is difficult because of gradations between different stages. The following eight stages or "degrees" of bloating were distinguished during the present study:

1. non-bloating, essentially no fusion.
2. non-bloating, but some fusion.
3. non-bloating, but highly porous, some slightly expanded, some slightly fused.
4. Bloated individual pellets well developed, slight fusion may occur at some samples.
5. Bloated, individual pellets strongly fused.
6. Bloated, individual pellets largely destroyed by fusion.
7. Bloated, highly porous, but toally fused.
8. Bloating is uncertain. Original rock fragments are totally fused and melted. Some porosity may be present.

On Figures 3, 5, and 6, the first three stages are considered as non-bloating clays and indicated by unshaded symbols. Stages 4 to 7 are considered as bloated clays and indicated by totally blackened symbols and Stage 8 is indicated by a half shaded symbol. If only a part of the samples from the same location bloated, it was still indicated by a black symbol. Two starlets placed after the degree of bloating indicate that the same sample has been previously bloated by Riley and has been considered as non-bloating. Three starlets indicate that corresponding samples bloated.

TABLE NO. 5. Abbreviations Used In The Tables.

B	(in the 4th vertical column only). Samples collected by K. F. Bickford
C.A.R.	County Aid Road
Cl	Clay
Cl-Sa	Sandy clay
Cl-Si	Silty clay
Cor.	Section corner
Cr.	Creek
Cret.	Cretaceous
Col.	Dolomite
E.	East
E	(in the 4th vertical column only). Samples collected by E. Bradley
ft.	feet
G.D.	gray drift
Glac. L.	Glacial lake
Hy 3	Minnesota State highway #3
L	lower part of a formation
Lam.	Laminated
Ls	Limestone
M	(in the 4th vertical column only). Miscellaneous samples owned by Minnesota Geological Survey.
M	middle part of a formation
me.	mile
N.	North
N.E.	north-east
NW	north-west
P	(in the 4th vertical column only). Samples collected by N. Prokopovich
Pi	pisolite
p(-	Precambrian
p(--R	Residual Precambrian clays
Quart.	Quarternary
R	(in the 4th vertical column only). Samples collected by C. M. Riley
R	River
RR	Railroad
Sa	sandy
S	South
S.A.R.	State Aid Road
SE	south-east
Si-Lam	Laminated silt
Sh	shale
SW	South-west
U	Upper part of a formation
U.S. Hy.	United States highway
v	very
W.	West
Wisc. G.D.	Wisconsin gray drift
Wisc. R.D.	Wisconsin red drift
$1^{\pm}$	Density about 1) in the 10th vertical column only.
1+	Density over 1) in the 10th vertical column only.
1-	Density below 1) in the 10th vertical column only.

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TABLE 6

Bloating Properties of Shale and Clay Samples

HOUSTON COUNTY

No.	Location	Source	Formation	Description before bloating	React. HCl.	Surface color after bloating	Int. Texture after bloating	Density	Rating
1	NW¼ 22:101-6 at Wilmington	Auger Sample	Decorah	Sh. dusky yellow*)	V. strong	Moderate brown	Coarse cellular	?	7?
2	SW¼ 15:102-6	Quarry, 5" layer in Dol.	Shakopee	Sh. greenish yellow to green	None	Moderate brown-olive green	Nonbloating	1+	1 to 2
3	NE¼ 5: 101-6, Hy. 44	Road cut	Decorah	Sh. pale olive *)	Positive	Moderate olive brown	Cellular, dark	1-	5
4	NW¼ 7: 101-6, N of Hy 44	Quarry in basal Prosser Ls.	Soil	Cl. light brown	(Strong)	Moderate brown	Non-bloating	1+	1
5	NE¼ 36: 102-7	Outcrop, 6" Sh. layer in dolomite, 15 ft. of Sh. in	Shakopee	Sh. grayish-yellow green	None	Light olive gray	V. fine cellular? possible slight bloating	1±	2?
6	SE¼ SW¼ 12: 101-7 Spring Grove	Overburden quarry in Plateville Ls.							
a		Upper part	Decorah	Sh. dusky yellow*)	None	Yellowish brown to olive gray	Moderate coarse cellular	1-	5
b		Lower part	Decorah	Sh. dusky yellow-pale olive	None	Yellowish brown to olive gray	Moderate coarse cellular	1-	5
c		2" "putty layer" at the top of Ls	Platteville	Cl. greenish-gray, fresh	V. strong	Light olive gray to white	V. coarse cellular	1-	5
7	NE¼ 17: 101-7, Hy 44 at R.R. underpass	About 17 ft. section of Sh.							

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color after bloating	Int. Texture after bloating	Density	Rating
a		Auger sample, upper part	Decorah	Sh. dusky yellow	None	Dark yellowish-brown	Moderate cellular, dark	1-	5 to 4
b		Auger sample, lower part	Decorah	" " "	V.strong	Light olive gray to brown	Coarse cellular, black, lime	1-	5?
c	Previous sampling	Top 5.5 ft.	Decorah	Sh. v. dark yellowish-brown		Moderate olive gray	Coarse cellular, some lime	1+	5**)
d		Middle 5 ft.	Decorah	Sh. v. dark yellowish-brown		Dark yellowish-brown	Fine cellular, dark, lime	1-	5**)
e		Lower 6 ft.	Decorah	Sh. v. dark yellowish-brown & grayish		Grayish-brown	Non-bloating, lime	1+	1**)

FILLMORE COUNTY

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color after bloating	Int. Texture after bloating	Density	Rating
8	SE$\frac{1}{4}$ 15: 101-8	Quarry in Platteville Ls. 3 ft. of Sh in overburden	L.Decorah	Sh. light olive brown	Strong	Moderate brown	Fine cellular	1$\pm$	5 to 4
9a	NE$\frac{1}{4}$ 21: 101-8	Road cut, Sh. 10 ft. above Platteville Ls.	M.Decorah	Sh. light olive brown	None	Grayish brown	Moderate cellular	1-	5 to 4
b		Road cut, Sh. just over Platteville Ls.	L.Decorah	Sh. dusky yellow*)	None	Dusky yellowish-brown	Moderate to coarse cellular	1-	6 to 7
c	at NE cor. 21	Road cut, 3 ft. cut	Glenwood	Sh. moderate grayish-yellow	None	Dark greenish-gray	Fine to moderate cellular	1-	5
10	NE$\frac{1}{4}$ 31: 101-8 at Riceford Cr., S. of Hy 44								
a		Auger sample	U.Decorah	Sh. dusky yellow	V.strong	Olive gray?	Coarse cellular, destroyed, much quicklime	?	3 to 7
b		Auger sample somewhat below "a"	U.Decorah	Sh. dusky yellow to pale olive*)	Strong	Olive gray	Coarse cellular, destroyed	1+?	8 to 7

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color after bloating	Int. Texture after bloating	Density	Rating
11	at $W\frac{1}{4}$ 23: 101-9 S bank of a Cr.	About 13 ft. of Sh. under soil covering							
a		Auger sample of slope	U?Decorah	Sh. pale olive to dusky yellow*)	Strong	Moderate brown to dark yellowish-brown	Fine cellular	1-	5
b		6 to 7 ft. below "a" at Platteville Ls.	L.Decorah	Sh. pale olive to dusky yellow*)	Positive	Dusky yellow brown to moderate brown	Moderate cellular	1-	5
12a	$NE\frac{1}{4}$ 32: 101-10	In Niagra Cave walls	Residium	Cl. moderate yellow brown	Poor	Dusky yellowish-brown	Fine cellular, gray	1+	4
b		In Niagra Cave Sh. layer in Ls.	Maquoketa	Sh. yellowish gray	V. strong	Dusky yellow	Fused, few quicklime	1+	8
13a	$NW\frac{1}{4}$ $SW\frac{1}{4}$ 32: 102-9	Poor outcrops on slope	Decorah	Sh. pale olive, rust stained*)	Strong	Olive gray	Fine to moderate cellular	1-	4
b		5 ft. below "a"	Decorah	Sh. dusky yellow to pale olive	Slight	Dusky yellowish-brown to moderate brown	Fine cellular, black	1-	5 to 4
14	Near $E\frac{1}{4}$ cor. 7: 102-9 N. of CAR 5	Hill slope	Decorah	Sh. light olive brown*)	Strong	Moderate brown	Fine cellular, black	1±	5 to 4
15	$NE\frac{1}{4}$ 5: 101-10 at CAR "F"	Hill slope toward Camp Cr.	Decorah	Sh. dusky yellow, stained*)	(Strong)	Grayish-brown	Fine cellular, black	1-	5
16	$SW\frac{1}{4}$ 24: 102-11 gully at cemetery	Outcrop 13 ft. of Sh. over Platteville Ls.	Decorah	Sh. pale olive*)	V. strong	Olive gray	Fine cellular	1-	5
17	9: 102-11	Hill slope outcrop	Decorah	Sh. dusky yellow to light olive brown	Strong	Dark yellowish-brown	Fine cellular	1-	4 to 5
18a	$SE\frac{1}{4}$ 19: 102-12 at Mystery Cave	S. Branch of Root River Sh. inter bedded with Ls.	Maquoketa	Sh. moderate yellowish-brown	V. strong	Moderate olive brown	V. coarse cellular, dark, few quicklime	1-	7

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color after bloating	Int. Texture after bloating	Density	Rating
b		In cave, 2" Sh. layer in Ls. bleached	Maquoketa	Cl. yellowish-gray	V.strong	Light olive brown	Totally fused, some cellularity, few spots of quick-lime	1+	8
c		in cave, the same layer but not bleached	Maquoketa	Sh. pale yellowish brown	V.strong	Light olive gray	V. coarse cellular, dark	1-	7
19	Near W$\frac{1}{4}$ cor. 14: 103-11 U. S. Hy. 52								
a		Old road, upper part	Decorah	Sh. pale olive	V.strong	Dusky yellowish-brown	Coarse cellular, dark	1-	5 to 4
b		Old road, lower part	Decorah	Sh. pale olive to dusky yellow	V.strong	Moderate brown to olive brown	Fine to coarse cellular, few quick-lime	1-	4 to 5
20	Near NW cor. 13: 103-11	Poor outcrop, about 36 ft. of Sh.	Decorah	Sh. pale olive*)	Moderate	Dark yellowish-brown	Fine cellular	1-	5
21	NW$\frac{1}{4}$ 9: 103-11 on CAR "E" at Rice Cr.	Road cuts, good 36 ft. section of Sh.							
a		Upper half (fresh)	Decorah	Sh. pale olive, rust stain*)	V.strong	Olive gray	Coarse cellular, black	1-	5 to 6
b		Lower half (fresh)	Decorah	Sh. light dusky yellow-green*)	V.strong	" "	Coarse cellular	1-	5
22a	Near E$\frac{1}{4}$ cor. 27: 104-11 on U.S. Hy. 52	Road cuts, auger sample	Decorah	Sh. light dusky yellow	V.strong	Light olive brown	Vitric, few pores, much quick-lime	1+	8
b		Near "a" lowermost 5.5 ft. of Sh.	L.Decorah	Sh.moderate brown to dusky yellow		Moderate brown to dusky yellow	Fine cellular, dark	1-	5***)
23	WE$\frac{1}{4}$ 30: 104-11	Outcrop on a slope	Decorah	Sh. light olive brown*)	V.strong	Grayish-brown	Fine to moderate cellular	1-	5 to 4

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color after bloating	Int. Texture after bloating	Density	Rating
24	SW$\frac{1}{4}$ 3: 103-12 at CAR "E" at Fillmore	Auger sample at a seepage on slope	Decorah	Sh. moderate yellowish-brown*)	Positive	Dark reddish-brown	Fine cellular, dark	1-	4 to 5
25a	W$\frac{1}{2}$ 13: 104-12 gully on S. bank of Lost Cr.	Just below Prosser Ls.	U. Decorah	Sh. dusky yellow to pale olive*)	V. strong	Dusky yellow brown	Coarse cellular, black, some quick-lime	1-	6 to 7
b		About 10 ft. below "a"	M. Decorah	Sh. dark pale olive*)	Strong	Dusky yellow brown	Fine to coarse cellular, black	1-	6
c		About 8 ft. below "b"	L. Decorah	Sh. light olive gray	None	Dusky yellow brown	Coarse cellular, gray	1-	5

MOWER COUNTY

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color after bloating	Int. Texture after bloating	Density	Rating
26 a	SW¼ 27: 101-14 at LeRoy	Quarry, 3" Sh. in limestone	Cedar V.	Sh. Grayish-yellow green	Positive	Moderate olive brown	Fine cellular, some lime	1+	6
b	SW¼ 33: 101-14	" "	" "	" "	"	Moderate olive gray	Coarse cellular	1-	6 to 7
27	NW¼ 33: 101-18 Cedar R., SAR 6	10' in river bank	Cretaceous?	Cl. varigated, white to red	None	Almost white	Non-bloating	1+	1
28	35: 102-18 U.S.Hy. 218	6' in road cut	Cretaceous?	Cl. yellowish gray	None	Dusky yellow to light brown	"	1+	1**)
29	NW¼ 26: 102-18	Quarry in Ls., Sinkhole filling	Cretaceous?	Cl. almost white	None	Almost white	"	1+	1
30	City of Austin	Basement excavation clay on limestone	Cretaceous?	" " "	None	" "	"	1+	1
31	30: 103-17	Stream bank	Cretaceous?	Cl. yellowish gray	None	Pale brown	"	1+	1**)
32	NE¼ 6: 102-16 S. bank Rose Cr.	7' clay at creek	Cretaceous?	Cl. almost white	None	Almost white	"	1+	1
				WINONA COUNTY					
33	SE¼ 34: 106-10	Road cut, above Platteville Ls.	Decorah or Residium	Cl. moderate yellow to brown	None	Dark Reddish-brown	Fine cellular, gray	1-	4

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color after bloating	Int.Texture after bloating	Density	Rating
34a	NW¼ 3: 105-10	Auger sample	Decorah reworked?*	Cl.moderate to pale olive gray*)	None	White gray to pale olive	Fine to coarse cellular	1-	5 to 4
b	Slope above spring	Outcrop	Decorah	Sh.moderate pale olive	(Some)	Olive gray to moderate brown	" "	1-	5
35a	E½ 18: 105-10 along Hy. 74	Uppermost road cut	Decorah	Sh.dusky yellow to pale olive	None	Dark Yellowish-brown	Fine cellular	1-	5
b		2" Putty layer in Ls.	Platte-ville	Cl.dusky yellow	V.strong	" "	Coarse cellular, much lime	1-	5 to6
c		Road cut below "b"	Glenwood	Sh.pale greenish-yellow	None	Moderate brown to pale olive	Moderate cellular	1-	4
36a	NE¼ 34: 105-10	Road cut upper part	U.Decorah	Sh.grayish-yellow to gray, stained*)	None	Light olive gray	Moderate to light cellular	1-	5
b		Road cut lower part	L.Decorah	Sh.dusky yellow	Strong	Moderate brown	Fine to moderate cellular, much lime	1-	5
c	At NE Cor. 34: 105-10	Road cut lower part	Glenwood	Sh.greenish-yellow to green	None	Light olive gray	Coarse to light cellular	1-	6

OLMSTED COUNTY

37	SE¼ 32: 105-11 S. of Hy. 74	Overburden in quarry in Platte-ville Ls.	Decorah	Sh.light olive*)	None	Moderate brown	Fine to moderate cellular	1-	5
38	SW¼ 32: 105-11 Hy 74 at Chatsfield								
a		Auger sample	Decorah	Sh.pale olive	(Some)	Dark to moderate brown	Moderate cellular	1-	4to5
b		Auger sample below "a"	Decorah	Sh.dusky yellow, stained	Strong	Moderate brown	Fine cellular, some lime	1-	5

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color after bloating	Int. Texture after bloating	Density	Rating
38c		Outcrop Hy, 2" "putty layer" in Ls.	Platteville	Cl.grayish-yellow	Strong	Yellowish-gray	Coarse to fine cellular	1-	4to5
39	NW¼ 20: 106-11 S. of U.S. Hy. 14	Terrace on slope							
a		Auger sample	Decorah	Sh.dusky yellow	None	Grayish-brown	Rather coarse cellular	1-	5
b		Auger sample below "a"	Decorah	Sh.dusky yellow, stained	(Some)	Grayish-brown	Moderate cellular, dark	1-	5to6
40a	16: 106-11 U.S. Hy. 14	Road cut upper 4 ft.	Decorah	Sh.grayish yellow	Strong	Moderate brown	Fine cellular, dark, much lime	1-	5***)
b		Road cut lower 4 ft.	Decorah	Sh.grayish yellow	Strong	" "	" "	1-	5?***)
41a	NW¼ 7: 106-11 at small swamp at a Cr.	Flat road cut	Decorah	Sh.light olive gray, some humus	None	" "	Moderate cellular	1-	4to5
b		At a creek below "a"	Decorah	Sh.pale olive	None	Dusky yellow to brown	Coarse cellular, dark	1-	5
42	11 or 13?: 107-12	7ft. cut at a Cr.	Loess	Grayish orange	None	Dark to pale brown	Non-bloating	1+	1***)
43a	NE¼ 9: 107-12	Hillslope. Field. Auger sample	Decorah	Sh.dusky yellow*)	None	Grayish brown	Coarse to fine cellular	1-	5
b		Auger sample 10ft. below "a"	Decorah	Sh.pale olive, stained	Positive	Dark yellowish-brown	Moderate to fine cellular	1-	5
44a	NW¼ 15: 105-12 Junction Hy. 52 & SAR 7	Road cuts	Basal Prosser or U.Decorah	Sh.-Lm., pale olive	V.strong	Yellow-gray to dusky	Earthy, much lime	1+	1?

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color after bloating	Int. Texture after bloating	Density	Rating
44b		Outcrop at seepage weathered	Decorah	Sh. dusky yellow	Positive	Moderate brown	Fine cellular, dark	1±	4
45a	Near SW cor. 22: 105-12 on W side at SAR 7	Road cuts 45 ft. section of Decorah Sh.	U.Decorah	Sh.pale olive, stained*)	(Strong)	Dark yellowish-brown to brown	Moderate cellular, some lime	1-	5to4
b			M.Decorah	Sh.pale olive	Positive	Light olive brown	Fine cellular, gray	1-	5
c			L.Decorah	Sh.light olive brown*)	Positive	Moderate brown	Fine cellular, dark, some lime	1-	4
46	SW¼ 15: 105-13 W.bank, Root R.	Outcrops of Sh. below Ls. cliff	Decorah	Sh.pale olive to dusky yellow*)	None	Light dusky yellow	Fine cellular, dark	1-	5
47	31: 105-14	Flat road cut	Cretaceous?	Cl.light pale olive	(None)	Light dusky yellow	Non-bloating	1+	1
48	S½ 6: 105-15 Creek bank, CAR "W"	Middle 5 ft.	Kansan G.D.	Cl.yellowish gray	Positive	Moderate brown	Fine cellular, poor bloating	1+	1 or 4***)
49	Central part of 32: 106-13	Outcrop in a creek bed	Cretaceous?	Cl.yellowish-gray	V.strong	Gray	Non-bloating	1+	1
50	NW¼ cor. 19: 106-13 on slope	Overburden in a quarry in Platteville Ls.							
a		Uppermost 2.5 ft. sh.	Decorah	Sh.light olive to pale olive, impure	None	Moderate brown	Fine cellular, dark	1-	5to6
b		Middle 5ft. Sh.	Decorah	Sh.pale olive*)	None	Dark yellowish-brown	Fine cellular, gray	1-	6
c		Lowermost 5 ft. Sh.	Decorah	Sh.pale olive	None	Grayish-brown	Coarse cellular, dark	1-	6
d		2" Putty layer at the top of Ls.	Platteville	Cl.grayish-yellow	None	Yellowish-gray	Fine light cellular	1-	5to6

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color after bloating	Int. Texture after bloating	Density	Rating
50e		1-1.5ft. oil Sh. layer at top of Ls.	Platteville	Sh. hard dusky yellow green, bituminous	V. strong	Light olive brown		1+	3
51	Near $W\frac{1}{4}$ cor. 19: 106-13 on slope	Outcrop in a gully	Decorah	Sh. fresh*) grayish green	(Strong)	Moderate brown	Coarse cellular	1-	7
52	Near $N\frac{1}{4}$ cor. 24: 106-14 isolated hill	Auger sample	Decorah	Sh. weathered dusky yellow	(Some)	Moderate brown	Coarse cellular to fused (good bloating at lower temperature)	2	7to8
53	$NE\frac{1}{4}$ 16: 106-14 W of SAR "p"	Above quarry in Platteville Ls.	L. Decorah	Sh. pale olive*)	None	Grayish-brown	Coarse cellular	1-	5
54	5: 106-13 S. of U.S. Hy. 14 at a motel	Small cuts	Glenwood	Sh. moderate grayish-yellow	None	Dusky yellow	V. fine cellular	1-	4to5
55	Near SE cor. 31: 107-14, S. of U.S. Hy. 14	Road cut & hill slope							
a		Topmost 5ft of exposure	Decorah	Sh. dusky yellow*)	(Some)	Dark yellowish-brown to moderate brown	Moderate cellular, some lime	1±	5
b		5ft. below "a"	Decorah	Sh. dusky yellow to pale olive	Strong	Light olive gray to moderate brown	Moderate cellular, dark	1-	5
c		3ft. below "b"	Decorah	Sh. dusky yellow	Positive	Dark yellowish-brown to moderate brown	Fine to coarse cellular	1-	5
d		10ft. below "c"	Decorah	Sh. pale olive*)	Positive	" "	Fine to moderate cellular	1-	5
e		Grab sample at a spring	Decorah	Sh. dusky yellow	(Positive)	Dark yellowish-brown	Fine cellular, dark	1-	5
f	Nearby in 32: 107-14	5.5ft cut on hill U.S. Hy. 14	Decorah	Sh. grayish yellow	Strong	Yellowish-gray	Earthy, some lime	1+	1**)

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color after bloating	Int. Texture after bloating	Density	Rating
56	Near W¼ cor. 29: 107-14 in quarry	From the bottom of Platteville quarry	Glenwood	Sh.moderate yellow-green	Strong	Moderate brown	Moderate cellular, dark	1-	4
57	Near S¼ cor. 8:107-14 at a creek	Auger sample in a meadow	Loess?	Cl.-Si pale olive, stained	(Small)	Dark reddish-brown	Fine cellular	1+	1?
58	SW¼ 13: 107-15 wet meadow	Auger sample	Loess?	Cl.-Si light olive brown	None	" "	Moderate cellular, gray to black, trace of bloating	1+	1 or 4?
59	Near N¼ cor. 11: 107-15	Auger sample	Kansan G.D.	Cl.light olive brown	None	" "	Moderate cellular dark	1+	1
60	NE¼ 10: 107-15 hill slope	Auger sample	Kansan G.D.	Cl.dusky yellow	V.strong	" "	Fine cellular, traces of bloating	1+	1?
61	NE¼ 18: 107-15 N. of Byron, N. of SAR 5 W. of S. middle branch of Zumbro R.	Quarry in Platteville Ls.							
a		Sh.just below drift	Decorah	Sh.moderate greenish-yellow, fresh	None	Moderate brown to pale olive	Coarse cellular gray	1-	5
b		Upper part of Sh. in overburden	Decorah	Sh.pale olive to dusky yellow	Positive	Dark yellowish-brown	Fine cellular	1±	4
c		Lower part of Sh. in overburden	Decorah	Sh.light olive gray, fresh	V.strong	Dusky yellow	Cellular, dusky yellow	1+	3?
d		2ft. layer of oil Sh. at top of Ls.	Platteville	Oil Sh.hard dark yellowish-brown	V.strong	White grayish-orange	Non-bloating	1+	1
e		2" Putty layer at the top of Ls.	Platteville	Cl.almost white, stained	None	Yellowish-gray to brown	Non-bloating	1+	2

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color after bloating	Int. Texture after bloating	Density	Rating
68a	SE¼ 3: 111-15 S. of Hy. 58 at Clay Bank	Cl. pit	Cretaceous?	Cl. light gray	None	Yellowish-gray	Non-bloating	1+	1
b		The same pit	Cretaceous?	Cl. yellowish-gray	None	" "	" "	1+	1
69A	W½ 21: 110-16 at Barr, S. of U.S.Hy. 52	Old Sh. pit	U.Decorah	Sh. light grayish-olive*)	None	Dark yellowish-brown	Fine to moderate cellular	1-	6
b			M.Decorah	Sh. pale olive	None	" "	Fine to moderate cellular, some places dark	1-	6?
c		The same pit top-most 5.5 ft.	U.Decorah	Sh. grayish yellow	Strong	Moderate brown	Non-bloating, some earthy aggregates	1+	3?**)
d		Next 5.5 ft.	Decorah	Sh. grayish yellow	Slight	White to brown	Fine cellular, gray	1-	4to5***)
e		Next 5.5 ft	Decorah	Sh. " "	Strong	Grayish-brown to gray	Destroyed, much lime	?	1**)
f		Lower 5.5 ft.	Decorah	Sh. " "	Strong	Moderate brown	Some fine cellular, much lime	1+	1?**)
70A	NE¼ 21: 110-17 Creek bank	Top 5.5 ft.	Decorah	Sh. yellowish gray	Strong	Dark yellowish to moderate brown	Coarse cellular, few lime	1-	6**)
b		Middle 5.5 ft.	Decorah	Sh. " "	"	Dark yellowish-brown	Coarse cellular,	1-	6**)
c		Lower 5.5 ft.	Decorah	Sh. grayish yellow	Positive	" "	Fine to moderate cellular, gray, some lime	1-	5to6**)
71a	35: 110-18 bank of Zumbro R. near Kenyon	Exposure of Sh. top 5.5 ft.	Decorah	Sample missing					
b		5.5ft. below "a"	Decorah	Grayish yellow	Strong	Light pale olive	Earthy, few lime	1+	1**)
c		5.5ft. below "b"	Decorah	" "	Strong	Dusky yellow to dark yellowish-brown	Fine cellular to earthy, destroyed, much lime	1±	5or6**)

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface Color after bloating	Int. Texture after bloating	Density	Rating
62	SW¼ 34 & SE¼ 33: 108-15, SAR 14 near Genoa	Road cuts							
a		Uppermost part of Sh.	U.Decorah	Sh.pale olive*)	V.strong	Dusky yellow	Destroyed, much lime	1+	7?
b		5ft. above Platteville Ls.	L.Decorah	Sh.pale olive	None	Moderate brown	Fine cellular, dark	1-	5
c		2" Putty layer in Ls.	Platteville	Cl.dusky yellow	Strong	Grayish-brown to moderate brown	Non-bloating	1+	1?
63	SE¼ 20: 108-15	Road cut near the top of the hill	U.Decorah?	Sh.pale olive, calcareous	V.strong	Moderate olive brown	Destroyed, much lime	1±	8 or 7?
64	W½ 20: 108-15 in a seepage	Outcrop	Decorah	Sh.light dusky yellow to light olive brown, some brushy oolites	(Strong)	Grayish-brown to moderate brown	Fine cellular, dark	1-	5

DODGE COUNTY

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface Color after bloating	Int. Texture after bloating	Density	Rating
65	N½ line 9-10: 108-16	15 ft. cut	Loess			Moderate brown	Non-bloating	1+	1***)

GOODHUE COUNTY

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface Color after bloating	Int. Texture after bloating	Density	Rating
66a	Near center 33: 111-14 at Belle Chester	Old clay pit	Cretaceous?	Cl.yellowish-gray	None	Yellowish-gray	Non-bloating	1+	1
b	" "	Top 5.4 ft.	Cretaceous?	Cl.grayish-yellow	None	Grayish-orange	"	1+	1**)
c	" "	Lower 5.5 ft.	Cretaceous?	Cl.grayish-yellow	None	V.pale orange with brown streaks	"	1+	1**)
67	N½ 26: 111-15 E. of Goodhue	Cl. pit	Cretaceous?	Cl.yellowish-gray	None	Yellowish-gray	"	1+	1

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color after bloating	Int. Texture after bloating	Density	Rating
68a	SE$\frac{1}{4}$ 3: 111-15 S. of HY. 58 at Clay Bank	Cl. pit	Cretaceous?	Cl. light gray	None	Yellowish-gray	Non-bloating	1+	1
b		The same pit	Cretaceous?	Cl.yellowish-gray	None	" "	" "	1+	1
69a	W$\frac{1}{2}$ 21: 110-16 at Barr, S of U.S.Hy. 52	Old Sh. pit	U.Decorah	Sh.light grayish-olive*)	None	Dark yellowish-brown	Fine to moderate cellular	1-	6
b			M.Decorah	Sh.pale olive	None	" "	Fine to moderate cellular, some places dark	1-	6?
c		The same pit, topmost 5.5 ft.	U.Decorah	Sh.grayish yellow	Strong	Moderate brown	Non-bloating, some earthy aggregates	1+	3?**)
d		Next 5.5 ft.	Decorah	Sh.grayish yellow	Slight	White to brown	Fine cellular, gray	1-	4 to 5***)
e		Next 5.5 ft	Decorah	Sh. " "	Strong	Grayish-brown to gray	Destroyed, much lime	?	1**)
f		Lower 5.5 ft.	Decorah	Sh. " "	Strong	Moderate brown	Some fine cellular, much lime	1+	1?**)
70a	NE$\frac{1}{4}$ 21: 110-17 Creek bank	Top 5.5 ft.	Decorah	Sh.yellowish gray	Strong	Dark yellowish to moderate brown	Coarse cellular, few lime	1-	6**)
b		Middle 5.5 ft.	Decorah	Sh. " "	"	Dark yellowish-brown	Coarse cellular	1-	6**)
c		Lower 5.5 ft	Decorah	Sh. grayish-yellow	Positive	" "	Fine to moderate cellular, gray, some lime	1-	5 to 6***)
71a	35: 110-18 bank of Zumbro R. near Kenyon	Exposure of Sh. top 5.5 ft.	Decorah	Sample missing					
b		5.5ft.below "a"	Decorah	Grayish yellow	Strong	Light pale olive	Earthy, few lime	1+	1**)
c		5.5ft. below "b"	Decorah	" "	Strong	Dusky yellow to dark yellowish-brown	Fine cellular to earthy, destroyed, much lime	1±	5 or 6**)

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color after bloating	Int. Texture after bloating	Density	Rating
		Missing interval 5.5 ft.							
71d		5.5 ft. above "e"	Decorah	Light yellowish-gray	Strong	Dusky yellowish-brown	Coarse irregular cellular, destroyed, much lime	1-	5?**)
e		Bottom 5.5 ft.	Decorah	Light yellowish-gray	Strong	Very dark yellowish-brown	Coarse cellular, few lime	1-	6 to 7**)
72	3: 109-18 at Kenyon	6 ft. Bank Pearl Cr.	Decorah	Light grayish yellow	Strong	Light pale olive	Earthy, some lime	1+	1**)
73a	3&4: 109-18 new junction Hy. 56 & 60 in Kenyon	Road cuts, weathered Sh.	Decorah	Sh. dusky yellow	Strong	Olive gray	V. coarse cellular	1-	7
b	" "	Fresh shale	Decorah	Sh. pale green	Strong	" "	Coarse cellular	1-	7
c	Nearby along Hy. 60 in Sec. 4	At a creek Sh. top 5.5 ft.	Decorah	Grayish yellow	Strong	Very pale orange with brown streaks	Non-bloating	1+	1**)
d		Middle 5.5 ft.	Decorah	Grayish yellow	Strong	Light brown, some fragments pale greenish-yellow	" "	1+	3?**)
e		Lower 5.5 ft.	Decorah	Grayish yellow	Strong	Light pale olive	Earthy, some lime	1+	1**)
74	SW¼ 10: 110-18 E. side of Hy. 56	Road cuts							
a		Sh. exposure at Little Cannon R.	U. Decorah	Sh. greenish-gray*)	V. strong	Dusky yellowish-brown	V. coarse cellular	1-	7
b		About 5ft. below "a"	U. Decorah	Sh. pale olive	V. strong	Pale yellowish-brown	Non-bloating, much lime	1+	1?
c	Nearby NW¼ 15: 110-18 at Hy. 56	At a creek	Decorah	Sh. grayish yellow	Strong	Very dark yellowish-brown	Coarse to fine cellular, some lime	1-	6 to 7**)

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color after bloating	Int. Texture after bloating	Density	Rating
75	Near E¼ cor. 8: 110-17 W. of SAR1, LS. quarry	3" Sh. layer in Prosser Ls.	Prosser	Sh. greenish-gray	Weak	Light olive gray	Moderate to coarse cellular, dark	1-	5
76	SW¼ 36: 111-17 at Hader	Overburden in Prosser Ls. quarry	Cretaceous?	Cl. light gray	None	Pale olive to moderate brown	Coarse light cellular	1-	5
77	SW¼ 14: 111-17 Ls. quarry	3" Sh. layer in Prosser Ls.	Prosser	Sh. greenish gray	Positive	Dusky yellow brown with light spots	Fine cellular	1-	5
78	NW¼ 6: 110-17 steep slope	Poor exposure of Sh.	Decorah	Sh. light olive brown	V. strong	Dusky yellowish-brown	Coarse cellular	1-	5 to 6
79	SW¼ 30: 111-17	Road cut 5 ft. of Sh.	Decorah	Sh. grayish yellow	Slight	Moderate brown	Moderate cellular, gray	1-	5***)
80	SE¼ 24: 111-18 & SW¼ 19: 111-17 N. side of SAR 9 E. of Soger	Road cuts on E. slope of Little Cannon R.							
a			U. Decorah	Sh. dusky yellow to pale olive*)	None	Dark yellowish-brown	Fine cellular	1-	4
b			M. Decorah	Sh. pale olive*)	None	Moderate brown	Fine cellular, dark	1-	4 to 5
c			L. Decorah	Sh. pale olive*)	None	Moderate olive	Fine cellular	1-	4 to 5
81	S½ 18 & NE¼ 21: 111-18 E. side of Hy. 56 NW of Wangs	Road cuts, thick section of Sh.							
a			U. Decorah	Sh. pale olive*)	None	Moderate olive brown to moderate brown	Fine cellular	1-	5?
b			M. Decorah	Sh. pale olive	Positive	Olive gray	Moderate to coarse cellular, dark	1-	6

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color after bloating	Int. Texture after bloating	Density	Rating
81c			L. Decorah	Sh, light olive brown to dusky yellow*)	Positive	Dark yellowish-brown to moderate brown	Fine cellular	1-	5 to 4
82a	Near SE cor. 6: 111-17 U.S. Hy. 52	Road cuts on a slope S. of a creek	U. Decorah	Sh. dusky yellow*)	Positive	Dark yellowish-brown	Fine to coarse cellular, much lime	1-	5 to 6
b		Top 5.5 ft. of exposure	Decorah	Sh. grayish yellow	Strong	Dark yellowish-brown to moderate brown	Fine cellular, dark	1-	5 to 6**)
c		Lower 5.5 ft. of exposure	Decorah	Sh. pale orange	Strong	Dark yellowish-brown	Coarse cellular, black, much lime	1-	6**)
83a	NE¼ 20: 112-17	Road cut Sh. top 5.5 ft.	Decorah	Sh. light yellowish gray	Strong	Moderate yellowish-brown to moderate brown	Moderate cellular, dark, some lime	1-	4 to 5**)
b		Sh. lower 5.5 ft.	Decorah	Sh. grayish yellow	V. Strong	Light pale olive	Earthy, some lime	1+	1**)
84	SE¼ 18: 112-17 in Cannon Falls N. of CAR 38	Small quarry in Platteville Ls.							
a		Upper part of Sh. in overburden	U. Decorah	Sh. fresh pale olive	None	Moderate brown	Fine to coarse cellular, black	1-	5
b		Lower part of Sh. in overburden	L. Decorah	Sh. dusky yellow	Positive	Olive gray	" "	1-	6
c		2" Putty layer in upper part of Ls.	Platteville	Cl. V. light gray	(None)	Yellowish-gray	Small porosity	1+	2
d	2nd quarry nearby	2" Putty layer in upper part of Ls.	Platteville	Cl. almost white	None	V. light gray	Light moderate cellular	1-	5 to 6
e		1 ft. bed of oil Sh.	Platteville	Oil Sh. hard yellowish-gray to dusky yellow	V. strong	Moderate grayish-yellow	Destroyed, much lime	1+	3?

RICE COUNTY

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color after bloating	Int. Texture after bloating	Density	Rating
85a	25-30: 111-19-20 4.4 mi. S. of Northfield	Upper 5.5 ft.	Decorah	Sh. grayish yellow	Strong	Moderate yellowish-brown	Non-bloating	1+	1**)
b		Lower 6 ft.	Decorah	Sh. " "	"	Dark yellowish-brown	Coarse cellular, dark	1-	5***)
86	SE¼ 34: 111-19 W. side of Hy. 246	New road cut, about 10 ft. Sec. of Sh.	Glenwood	Sh. dark grayish-yellow-green	Positive	Moderate olive gray	Coarse cellular	1-	6 to 7
87	SE¼ 16: 110-19 W. side of Hy. 246	Outcrop at the bottom of gulley	Kansan G.D.	Cl. moderate gray	Strong	" "	Coarse cellular	1-	6 to 7
88a	6: 109-20 old Lieb's Ls. quarry	Top 5 ft.	Decorah	Sh. light yellowish gray	Slight	V. dark yellowish brown	Moderate cellular	1-	5***)
b		Lower 5 ft.	Decorah	Sh. yellowish gray	Strong	" "	Coarse cellular, few non-bloating particles	1-	6**)
89	Near SE cor. 17: 109-21 gravel pit	12 ft. of drift gravel composed of fragments of Cretaceous Sh.	Wisc. G.D. Cretaceous	Sh. moderate yellowish-gray	None	Grayish-orange	Coarse cellular	1+	1

DAKOTA COUNTY

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color after bloating	Int. Texture after bloating	Density	Rating
90	NW¼ 6: 113-17 E. side of CAR 18	Posthole at a farm	Decorah	Sh. dusky yellow	None	Dark yellowish-brown	Fine to moderate cellular	1-	5
91a	Near E¼ cor. 28: 28-32 SE of Mendota Br. S. of Hy. 55	Roadcut, somewhat weathered upper part	Decorah	Sh. pale olive, stained, weathered	Positive	Dusky yellowish brown	Fine to moderate cellular, dark, some lime	1-	5
b	" "	Fresh lower part	Decorah	Sh. pale olive, fresh	Positive	Moderate brown	Fine cellular, dark	1-	5 to 4

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color after bloating	Int. Texture after bloating	Density	Rating
91c	Near E¼ cor. 28: 28-32 SE of Mendota Br. S. of Hy. 55	Top 6 ft.	Decorah	Sh. pale olive, fresh	Positive	Dark yellowish-brown	Fine cellular, dark some lime	1-	5***)
d	" "	Lower 6 ft.	Decorah	" "	"	Olive gray	Fine to moderate cellular	1-	7***)

RAMSEY COUNTY

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color after bloating	Int. Texture after bloating	Density	Rating
92a	7: 28-28 pit of Twin City Brick Co.	Topmost 15 ft.	Decorah	Sh. light greenish gray	Strong	V. dark yellowish-brown	Coarse cellular	1-	7**)
b		Next 12 ft.	"	" "	Strong	" "	V. coarse cellular	1-	7**)
c		Next 12 ft.	"	Sh. light gray	Strong	Dark yellowish-brown	Moderate cellular, gray	1-	6***)
d		Next 12 ft.	"	Sh. very light gray	Slight	" "	" "	1-	6***)
e		Lower 19 ft.	"	Sh. light greenish gray	None	" "	" "	1-	6***)

CARVER COUNTY

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color after bloating	Int. Texture after bloating	Density	Rating
93	U.S. Hy. 212 opposite to Shakopee	Roadcut in Minnesota R. valley	Glac. L.	Lam. Cl.-Si. light buff silt	None	Light olive gray	Irregular cellular some lime	1+	6
94a	NW¼ 33: 116-23 N. of Chaska	Pit?	Wisc. G.D.	Cl. light olive gray, pebbly	Strong	" " "	Moderate to coarse light cellular	1+	5 to 6
b	Clay pit 1 mi. N. of Chaska	7 ft. wall	Glac. L.?	Cl. yellowish gray	Moderate	Dusky yellow	Non-bloating, some particles	1+	1**)

LE SUEUR COUNTY

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color after bloating	Int. Texture after bloating	Density	Rating
95*	2.6mi. N. of LeSueur	Roadcut on U.S. Hy. 169	Kansan G.D.	Cl. moderate to dark gray (with fragments of gray Sh.	None	Dusky yellow	Non-bloating	1+	1

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color after bloating	Int. Texture after bloating	Density	Rating
96	NE¼ 36: 109-24 new large gravel pit	Drift gravel composed of fragments of Cretaceous Sh.	Wisc.G.D. Cretaceous	Gravel of yellowish-gray Sh.	None	Grayish-orange	Coarse cellular	1+	1

BLUE EARTH COUNTY

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color after bloating	Int. Texture after bloating	Density	Rating
97	SE cor. T: 108-25 at Indian Lake	Possible reworked deposit of Cretaceous Sh.	Cretaceous?	Sh."red", (light brown)	None	Grayish-brown	Non-bloating	1+	1 or 3
98	SW¼ 35: 108-27 on Hy.256 W.bank of Le Sueur R.	Road cut	Cretaceous?	Cl.almost white	None	V.pale orange	" "	1+	1
99a	NW¼ 8?: 107-27 E.end of Rajndan dam		Glac. L.	Cl.-Si. Lam. yellowish-gray	Strong	Moderate olive	Some porosity	1+	2
b			Quarternary	Cl.gray olive	Some	Grayish-olive	Coarse cellular, much lime	1+	7

NICOLLET COUNTY

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color after bloating	Int. Texture after bloating	Density	Rating
100	Minnesota R. valley opposite the mouth of Blue Earth R.on U.S.Hy 14	Roadcuts & cliff							
a		Roadcut top	Wisc.G.D.	Cl.light olive gray	Strong	Dusky yellow	Coarse irregular cellular, some lime	1+	7 or 8
b		Roadcut below "a"	Wisc.G.D.	" " "	"	" "	Non-bloating, much lime	1+	1 or 2? (maybe 8)
c		Roadcut below "b"	Kansan G.D	Cl.yellowish to brownish-gray	V.strong	" "	" " "	1+	2?

No.	Location	Source	Formation	Description before bloating	React.	Surface color after bloating	Int. Texture after bloating	Density	Rating
101*)									
a	NE$\frac{1}{4}$ NW$\frac{1}{4}$ 14: 108-27, N. bank Minnesota R.		Residium?	Cl.-Si yellowish gray	V.strong	Dusky yellow	Non-bloating	1+	2
b			Blue Earth	Sh.-Clayey white to pale greenish gray	None	Dusky yellow with reddish stain	" "	1+	1
c			BlueEarth	" " "	None	Grayish-yellow	" "	1+	1
102*)	T110-30 $\frac{1}{2}$ mi. S. of junction on U.S. Hy. 14 & 15	High cl. bank	Kansan G.D.	Cl-Si moderate to dark gray	None	Light olive gray	V.coarse cellular	?	7 or 8
103 a - f	1: 111-33	Test hole top to bottom	pC - R	Cl.pale yellowish orange	None	Grayish orange pink, with dark reddish	Non-bloating	1+	1

RENVILLE COUNTY

A total of 85 samples from locations 104 to 114 were tested with negative results. These were all either residual clays on Precambrian rocks or somewhat transported and redeposited presumably in Cretaceous time.

REDWOOD COUNTY

A total of 85 samples from locations 115 to 129 were tested with negative results. These were all either residual clays on Precambrian rocks or somewhat transported and redeposited presumably in Cretaceous time.

BROWN COUNTY

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color after bloating	Int. Texture after bloating	Density	Rating
130a	NW¼ 3: 111-33	Road cut Upper 4 ft.	pC - R	Cl. light buff (granular)	None	Pale red some iron stain	Non-bloating	1+	1
b	near creek	2.7 ft.	" "	" " "	"	Almost white (grayish) black stain	" "	1+	1
c		2.7 ft.	" "	Cl. light gray to almost white	"	" "	" "	1+	1
d		3.7 ft.	" "	Cl. V. light buff to almost white	"	V. pale orange	" "	1+	1
131	New Ulm 7th St. Sol & German St.	Excavation	Recent	Si-Sandy dark brown orange	"	Pale reddish-brown	Non-bloating (sandy)	1+	1
132*) a	New Ulm brick yard	Stockpile, excavated in a pit along Minnesota R.	Cretaceous	Cl. dark gray, plastic	"	Moderate olive brown to olive gray	Coarse cellular	1+	7
b	at New Ulm upstream from old br. on Cottonwood R. NW¼ 23: 110-30	Dump	Cretaceous	Cl. & Si indurated moderate gray	"	Light olive gray to grayish olive	Irregular cellular	1+	4
c	" " "	Exposure on dirt road	"	Cl. moderate gray, plastic	"	Light gray	Earthy	1+	1
d	" " "	" " "	"	Indurated Si-Cl. gray	"	V. dark yellowish-brown	Sandy	1+	1
133*)	1.8mi. E of Sleepy Eye NE¼ 34: 110-32	Gully at old road	Wisc. G.D.	Cl. gray	"	Light olive gray	Fragments destroyed much lime	1+	1?
134*)	SW¼SW¼ 31: 110-33 on U.S. Hy. 14 W. of Cobden	Bank of Sleepy Eye Cr.	Wisc. G.D.	Cl. almost gray, gritty	"	Dusky yellow	Coarse cellular, some lime	1+	7 to 8

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color after bloating	Int. Texture after bloating	Density	Rating
135*)	NE$\frac{1}{4}$ 17 & NW$\frac{1}{4}$ 16: 109-35, at Springfield, Old pit of A.C. Ochs Brick & Tile Co.	Section of pit according to Bradley (1949)							
		Drift 0-10 ft.	Quarternary	Not sampled					
a		Clay 10-16 ft. (reworked)	Cretaceous	Cl.dark gray, some rust stain	None	Pale brown	Black, non-bloating	1+	1
b		" " " " (in place)	"	Cl.dark gray	"	Grayish-red	Fine cellular, black	1-	4
c		Lignite 16-17 ft.	"	Not sampled					
		Clay with lignite 17-17.5	"	Cl.moderate to dark gray	None	Pale yellowish-brown	Fine cellular, gray	1±	4
		Sand 17.5-20	"	Not sampled					
d		Clay 20-30	"	Cl.yellowish gray	None	" "	" " "	1+	4?
e		" " "	"	Cl-Si light olive gray	Slight	" "	" " "	1±	4
f		Sand below	"	Not sampled					
136a	NE$\frac{1}{4}$ 26: 109-35 New pit of A.C. Ochs Company at Springfield	Grab sample	"	Sh.to Cl.moderate gray	None	Gray-brown	Coarse cellular, dark	1-	4 to 5
b		" "	"	Sh.to Cl.moderate yellowish-gray	"	Moderate yellowish brown	V.fine cellular, dark	1±	4

PIPESTONE COUNTY

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color after bloating	Int. Texture after bloating	Density	Rating
137	Pipestone Quarry 1: 106-41 at Pipestone	16-20" Sh.layer in Sioux quartzite	pC	"Pipestone" siltstone	None	Pale red	Non-bloating	1+	1

YELLOW MEDICINE COUNTY

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color after bloating	Int. Texture after bloating	Density	Rating
138	At Granite Falls	In Minnesota R. Valley	pC-R	Cl.pale reddish-brown with yellowish mottling fat, over granite	None	Dark reddish-brown	Non-bloating	1+	1

HENNEPIN COUNTY

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color after bloating	Int. Texture after bloating	Density	Rating
139	3-4 mi. NW of Hamel		Recent	Impure marl, pale olive	V.strong	Moderate olive brown	Coarse cellular, dark to light	1-	7

ANOKA COUNTY

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color after bloating	Int. Texture after bloating	Density	Rating
140	Coon Creek area		Glac.L?	Cl-Si light brown	Positive	Dusky yellow brown	Coarse cellular	1+	5
141	15: 31-24	Old pit near NRRR	Glac. L.	Cl. Lam		Grayish-brown	" "	1+	6***)
142a	Cl.pit 1.8 mi. S of intersection of Hy 10 & 56	12 ft. above "b" in pit	Glac. L.?	Cl.light olive gray	Slight	Moderate olive brown	Irregular cellular, much lime	1+	5
b		Bottom of the pit	Glac. L.?	" " "	Strong	" "	Coarse cellular	1+	5 to 6
c		Water level sample	Glac. L.?	Cl.sandy medium light gray	None	Moderate brown	Sand & pebbles	1+	1

SHERBURNE COUNTY

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color after bloating	Int. Texture after bloating	Density	Rating
143a	1 mi. E of Elk River	Auger sample 1.5 - 2 ft.	Wisc.GD?	Cl.moderate gray, stained	None	Olive gray to moderate olive brown	V.large cellular	1+	7
b		2.5 - 3 ft.	Wisc.GD?	Cl.moderate gray with sandy streaks	"	Olive gray?	Coarse cellular	?	7?

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color after bloating	Int. Texture after bloating	Density	Rating
143c		3 - 4.5 ft.	Wisc.GD?	Cl.moderate gray stained wet	None	Moderate olive brown to olive gray	Irregular cellular	1±	6

WRIGHT COUNTY

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color after bloating	Int. Texture after bloating	Density	Rating
144	2 mi. E ¼ mi. S of Maple Lake	From shore of the lake near Hy.55	Wisc.G.D.	Cl.grayish-orange	None	Moderate brown	Non-bloating	1+	1 to 2

STEARNS COUNTY

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color after bloating	Int. Texture after bloating	Density	Rating
145	4 mi. E. of Paynesville at W.end of Rice Lake	Old brick yard	Wisc.GD?	Cl.light olive gray	Slight	Light olive gray	" "	1+	2
146	W of Richmond W of bridge	River bank	Creta-ceous?	Cl.brownish gray, some organic matter	Strong	Olive gray	Irregular to coarse cellular	1-	7
147a	Near Richmond on St.Cloud Hy.23 300 ft.	Auger sample, upper 1.11 ft.	Cretaceous	Cl-Pi light gray, iron stain	None	Almost white (v.pale orange)	Non-bloating	1+	1
b	From the bridge at Sauk R.	2.2 ft.	"	Cl-Pi light greenish-gray	"	Grayish-white, some dark stain	" "	1+	1
c		1 ft.	"	" " "	"	Grayish-orange	" "	1+	1
d		3 ft.	"	Cl.light gray	"	Pale orange to almost white	" "	1+	1
e		3 ft.	"	Cl.light gray, much iron stain	"	V.pale orange, dark spots	" "	1+	1
f		2 ft.	"	Greenish-gray to moderate light	"	Light brown	" "	1+	1
g		2.2 ft.	"	" " "	"	" "	" "	1+	1
h		1.7 ft.	"	" " "	"	" "	" "	1+	1
i		2.2 ft.	"	" " "	"	" "	" "	1+	1

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color After bloating	Int. Texture after bloating	Density	Rating
148a	SE of St. Cloud Beutler Cl. pit	1ft.below surface	Glac.L?	Cl.light brownish-gray	V.strong	Dusky yellow	Non-bloating	1+	2
b	W of Hy. 152	Bottom of the pit	Glac.L?	Cl.yellowish-gray	None	Olive gray to moderate olive brown	" "	1+	8
149	Near St.Cloud E of Hy.152 Hiss Cl. pit		Glac.L?	Cl-Si yellowish-gray	Strong	Dusky yellow	" "	1+	2
150	At Sauk Centre	Pit 2mi.N of intersection USHy 71&Hy 28 at Sauk Lake	Glac. L.	Cl-Lam yellowish-gray	V.strong	Light olive gray	Fine cellular	1+	8

TODD COUNTY

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color After bloating	Int. Texture after bloating	Density	Rating
151	3 mi. E & ½ mi. S of Carissa, old clay pit		Wisc. G.D.	Cl-Sa, light gray	None	Yellowish gray	Sandy & non-bloating gravels	1+	1
152a	1.5 mi E of Staples on US Hy 10 N. of RR		Wisc.G.D.	Cl-Sa yellowish gray	"	Moderate grayish brown	Coarse cellular	1-	4
b	Nearby	1/8 mi. E of "a"	Wisc.G.D.	" "	"	" "	" "	1-	4 to 5

MORRISON COUNTY

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color After bloating	Int. Texture after bloating	Density	Rating
153	2.5 mi W of Little Falls near Hy. 27	Ditch near old brick yard	Glac. L.	Cl-Lam light olive gray	V.strong	Light olive-brown	Non-bloating	1+	2
154	3.7 mi S. of Little Falls	30 ft.bank in Meander of Mississippi R.	Wisc.G.D.	Cl.yellowish gray	Strong	Moderate olive brown	Moderate cellular, some samd, some lime	1+	6

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color after bloating	Int. Texture after bloating	Density	Rating
155a	3 mi N. of Royaltown Bonlus road ½ mi. W of Mississippi R.	Highway post	Wisc.R.D.	Cl-Sa pale-yellowish brown	None	Grayish-red	Non-bloating Pebbles & sand	1+	1
b			Wisc.R.D.?	Cl. V.pale orange	V.strong	Moderate reddish-brown to dark yellowish-brown	" " "	1+	1
156a	NW¼ 8: 127-29 W.bank of Mississippi near bridge on Hy. 1		Cretaceous	Bauxite gray to moderate brown	None	Blackish red to moderate red	Non-bloating	1+	1
b		9.7 ft	"	Cl-Pi light gray almost white	"	V.light gray	" "	1+	1
c		2 ft.	"	Cl.dark to moderate brown	"	Dark reddish-brown	" "	1+	1
d		2 ft.	"	" " " "	"	" "	" "	1+	1
e		3.5 ft.	"	Cl.moderate gray brown, with iron stain	"	Grayish Red	" "	1+	1
f		2.5 ft.	"	Cl.light gray with iron stain	"	Moderate reddish-brown to almost white	" "	1+	1

MILLE LACS COUNTY

157	1/8 mi N. of Long Siding along U.S. Hy. 169	Ditch	Glac. L.?	Cl.moderate gray, stained	None	Moderate olive brown	Moderate cellular, (heavy)	1+	5
158a	N.or Onamia at US Hy.169	Road citch,clayey soil	Wisc.R.D.?	Si dark gray, iron stain	None	Grayish-brown	Non-bloating	1+	1
b		Sandy Cl.below "a"	Wisc.RD	Cl-Sa moderate reddish gray, much stain	None	Dark reddish-brown	Non-bloating, sandy	1+	1

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color after bloating	Int. Texture after bloating	Density	Rating
159a	N. or Onamia at US Hy.169	Road ditch, clayey soil	Recent	Cl. moderate	None	Light olive gray	Moderate cellular	1+	5
b			Wisc.RD?	Si.dark brown	"	Moderate brown	Non-bloating sandy	1+	1

CROW WING COUNTY

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color after bloating	Int. Texture after bloating	Density	Rating
161a	T.47-28 E drained end of Rabbit Lake	Low grade marl, lake bottom	Recent	Cl.moderate gray	None	Olive gray	V.coarse cellular	?	7 or 8
b		Lake bed below marl	"	" " "	"	Dusky yellowish-brown	Coarse cellular	1-	7 or 6
c		Patrician red drift	Wisc.RD	Cl.reddish-brown	"	Blackish-red	Excellent moderate cellular	1-	7
d		Somewhat lighter than "e"	KansanGD	Cl.yellowish brown to light dark gray	Strong	Grayish-brown	Fine cellular	1+	2?
e		Old gray drift	Nebraskan GD	Cl.moderate gray	None	Dusky brown	Irregular cellular	1+	5

AITKIN COUNTY

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color after bloating	Int. Texture after bloating	Density	Rating
162a	N.of Aitkin meander of MississippiR.	3 ft.Cl.layer	Glac.L?	Cl-Si gray dark, organic	None	Dark yellowish-brown	Coarse cellular	1-	5
b			" "	Cl.moderate gray	"	Grayish-brown	Non-bloating	1+	1
163*)									
a	NE of Aitkin bank of Mississippi R. at bridge on US Hy169, NE¼ 10: 48-26	1 ft. below surface	Recent?	Cl.moderate grayish-brown	"	" "	Irregular cellular	1+	5?
b		Below	Glac.L	Cl-Si Lam. moderate grayish-brown	"	" "	Non-bloating	1+	2?
c		Below	" "	Cl.moderate gray, some iron stain	"	" "	Irregular cellular	1+	4
d	¼ mi. S. of samples of a, b, c	Ditch in a field, W. of Hy.	" "	Cl.moderate gray, sticky	"	Dusky yellow to olive gray	Some porosity	1+	2 or 8

CARLTON COUNTY

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color after bloating	Int. Texture after bloating	Density	Rating
164*)									
a	Nemadji clay pit SW¼ NW¼	1ft.below surface	Recent	Cl.moderate brown (soil horizont "B")	None	V.dusky red	V.fine cellular	1-	4
b	14: 36-18	7ft.below surface	Glac.L.	" " "	"	Olive gray	Fine cellular	1+	8
165*)									
a	Blackhoof post NW¼ 26: 47-17		Glac.L.	Cl.reddish brown	None	Moderate olive brown	Non-bloating	1+	2?
b	N.bank Blackhoof R.		" "	Cl.moderate brown	"	Dusky yellowish-brown	Irregular cellular	1+	6
c			" "			Olive gray	Coarse cellular	1+	8
d			" "			Light olive brown to olive gray	Light to dark, partially cellular	1+	8
166*)									
a	28: 48-16 Wrenshal pit	From dodge plant Moose Lake	Glac. L.	Brick moderate brown	None	Light olive brown to dusky yellow	Some coarse cellular	1+	2
b		Overburden	Recent	Cl.brown, some humus	"	Dusky yellow	Non-bloating	1+	2
c		5ft.below surface	Glac. L.	Cl-Lam red and grayish brown	"	Moderate olive brown	Non-bloating(solid)	1+	8
d		20ft.below surface	" "	Cl-Lam red & grayish brown	"	" "	" " "	1+	8
e	W.	W.edge of the post, 15 ft.	" "	Cl.Lam dark gray	"	Light olive brown	Solid to coarse cellular	1+	2 & 7 or 8
167*)									
a	Kelly pit 20: 48-16 0.5 mi.		Glac. L.	Cl-Lam dark gray	"	Dusky yellow	Non-bloating	1+	1 to 2
b	S of Wrenshall on aid road #1		" "	" " " "	"	Light olive brown	Solid to coarse cellular	1+	2 few 8
c			" "	" " " "	"	Dusky yellow	Non-bloating	1+	2

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color after bloating	Int. Texture after bloating	Density	Rating
168*)	Jay Cooke St. Park 0.5 mi. from Thompson entrance 8: 48-16		Glac. L.	Cl.sticky "red"	None	Dusky yellowish-brown	Moderate to excellent cellular	1-	6 to 7
169	Jay Cooke St. Park	Outcrop of red sh. & ss of Fonnd du Lac beds	pC	Sh.brownish-red	"	Light reddish-brown	Non-bloating	1+	1
170*)	Cloquet N. of St.Louis R 14: 49-17 at Hy33		Wisc.RD	Grayish-brown ("red") gritty	"	Moderate olive brown	" "	1+	7 to 8

LAKE COUNTY

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color after bloating	Int. Texture after bloating	Density	Rating
171	At Beaver Bay	Shore of Lake Superior	pC	Hard fresh amarthosite, almost white	None	Almost white	Non-bloating	1+	1

ST. LOUIS COUNTY

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color after bloating	Int. Texture after bloating	Density	Rating
172	$NW\frac{1}{4}$, $NW\frac{1}{4}$ 35: 51-19 2 mi. E. of Paupores	Clay bed in a gravel pit	Valders RD	Cl. reddish-brown	Strong	Dusky red	Slightly cellular	1+	3?

ITASCA COUNTY

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color after bloating	Int. Texture after bloating	Density	Rating
173a	Dear R. & Dear Lake	Described by Winchell	Cretaceous?	Cl.yellowish-gray	V.strong	Moderate olive brown	Moderate cellular	1+	5 to 6
b			"	" " "	" "	Grayish olive	Coarse cellular	1+	7
174a	24: Bamsting twp-T-R		Wisc.GD	Si-grayish-yellow	" "	Dusky yellow	Non-bloating	1+	2?
b			" "	Cl.yellowish-brown	Strong	Dusky yellowish-brown	V.coarse cellular	1-	7
175	1 mi. W of Effie	Ditch	" "	" " "	V.strong	Olive gray	Coarse cellular	1+	7

KOOCHICHING COUNTY

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color after bloating	Int. Texture after bloating	Density	Rating
176	7 mi E of Northhome on Hy. 71		Wisc. GD	Cl.yellowish-gray	V.strong	Light olive brown	Non-bloating	1+	8

BELTRAMI COUNTY

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color after bloating	Int. Texture after bloating	Density	Rating
177	N. of Bemidji at seaplane base	Lake bank	Glac. L?	Calcareous clay yellowish-gray	V.strong	Light olive brown	Non-bloating	1+	2
178a	Bemidji brick-yard	1ft. below top	Glac. L.	Cl-Lam yellowish gray	" "	Grayish-yellow	" "	1+	1
b		5 ft. below "a"	" "	" " "	" "	Dusky-yellow	Coarse cellular	1+	8?
c		below "b"	" "	Cl.light gray, "blue clay"	" "	Moderate olive brown to olive gray	" "	1−	8 to 7

HUBBARD COUNTY

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color after bloating	Int. Texture after bloating	Density	Rating
179a	A.Kelly Moore clay pit	Red "Gumbo clay"	Glac. L?	Light buff, large pieces	None	Grayish-brown to light-brown	Non-bloating	1−	1
b		2 ft. below "a"	Glac. L.	Cl.Lam light brown	None	Dusky yellow to pale yellowish-orange	" " (large fractures)	1+	2

MARSHALL COUNTY

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color after bloating	Int. Texture after bloating	Density	Rating
180	Warren $\frac{1}{2}$ mi. N. of old brickyard E. of RR		Glac.L.	Cl-Sa yellowish-gray	V.strong	Yellowish-gray	Non-bloating(sandy)	1+	1

POLK COUNTY

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color after bloating	Int. Texture after bloating	Density	Rating
181a	E of Grand Forks near US Hy 2	Old brick yard at river bank	Glac.L	Cl.light olive gray	Strong	Dusky yellow to light yellow-gray	Coarse cellular, some lime	1+	8

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color after bloating	Int. Texture after bloating	Density	Rating
181b		Old brick yard at river bank	Glac. L.	Cl.light olive gray	Strong	Light olive gray to dusky yellow	Moderate to fine cellular	1+	5?
182a	Crookston near US Hy 75 S of Main Str.	Old brickyard	Glac. L.	Cl.dark to light olive gray	V.strong	Light olive gray	Some porosity	1+	8
b		" "	" "	Cl.yellowish-gray	" "	Dusky yellow to light yellow-gray	Irregular to coarse cellular	1+	8
183a	Fertile clay pit	3ft.below surface	Glac. L.	" " "	" "	" " "	Solid, some cellular	1+	8
b		12 ft. below surface E. pit	" "	Cl.pinkish-gray	" "	Dusky yellow	Non-bloating	1+	2
c		12 ft. below surface W pit	" "	" " "	" "	Moderate olive brown	" "	1+	2 or 8
d		Si-Sa-Cl W. pit bottom	" "	Cl.yellowish-gray	" "	Dusky yellow	" "	1+	1
				BECKER COUNTY					
184a	1.5 mi SW of Detroit Lake	Roadcut on Northern Lights road	Wisc.GD?	Cl.grayish-brown	None	Light olive brown	None to coarse cellular	1+	1 & 7
b			" "	Cl.moderate gray	None	" "	Coarse cellular, gray	1+	5?
				OTTER TAIL					
185	Pelican Rapids N.edge of the town	Near watertower	Wisc.GD	Cl.light buff, medium pieces	None	Dusky brown to dusky yellow	Coarse to solid cellular	1±	1 or 8
186	2 mi. W of Perham	Old brickyard	Wisc. GD	Dirty brown large pieces	None	Pale reddish to dark reddish brown	Coarse cellular (v.poor bloating)	1+	4

No.	Location	Source	Formation	Description before bloating	React. HCl	Surface color after bloating	Int. Texture after bloating	Density	Rating
187a	2 mi. W & 2.7 mi N. of		Glac. L.	Cl-Lam light buff, large pieces	None	Dusky yellow	Non-bloating	1+	2?
b	Dear Creek	5 ft. below "a"	Glac. L.	" " " "	"	" "	" "	1+	1
c	0.8 mi. W of old Dear Creek brickyard	Roadcut of secondary road	Wisc.GD?	" " " "	"	Yellowish-gray to dusky yellow	" " (sandy), much lime	1+	1
188	Fergus Falls, Cascade Str. S. of town	Old brickyard	Wisc.GD?	Cl.light burr, large pieces	"	Dusky yellow	Non-bloating, fracture, lime	1+	2?