SECTION IV, 1924 [9] TRANS. R.S.C.

The Clays of the Lake Agassiz Basin

I. THEIR COLLOIDAL CONTENT

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(Read May Meeting, 1924)

INTRODUCTORY

Lake Agassiz covered an area of great extent during the retreat of the last ice sheet towards Hudson Bay. Its area at any stage has not been defined with accuracy; for its northern boundary was the retreating ice wall. At its greatest height it covered almost the whole of southern Manitoba, and part of North Dakota and Minnesota; and the place where Winnipeg now stands was over 500 feet below the surface of the lake. The lowering of the lake was not a gradual process, but was interrupted by many breaks, of sufficient duration to permit of well defined beaches being formed on the shores of the lake. These beaches are clear cut topographical features of the present surface of southern Manitoba, more particularly along the foot of the Manitoba escarpment on what was the western shore of the lake. The area is not yet completely drained out, for Lake Winnipegosis, Lake Manitoba and Lake Winnipeg are the present-day representatives of this great inland sea; the obstacle to further lowering of the waters being not a receding ice-sheet, but the Precambrian ridges which only slowly give way before the erosive force of the Nelson river, through which the system now empties into Hudson Bay.

In a freshwater basin of such considerable extent conditions are favorable for the study of freshwater sedimentation. At the low temperature of a glacial lake the salt content in the water is low, for rock disintegration has been limited. The action of electrolytes in precipitating sediment is therefore reduced to a minimum. During the melting season glacial rockflour and other rock sediment is poured into the lake by fluvioglacial streams and from land rivers: in the winter such contributions cease, and time is given for the finer sediments to settle undisturbed. Particularly in the deeper parts of the lake, as where Winnipeg now stands, undisturbed by local fluctuations the sedimentation of the summer and the winter periods should register itself in the clays now exposed to view: and evidence should be available to assist in interpreting the freshwater sedimentation process and the conditions that obtained during Lake Agassiz times.

The Clays of the Winnipeg Area

The clays deposited in the Lake Agassiz basin would appear to be somewhat limited in thickness in Southern Manitoba, except in restricted areas. Good sections are not, however, easily available, and attention has, for the present, been confined to the Winnipeg area, where sections are exposed by excavation or on the river banks, and where the thickness of the clays is considerable. It is planned to extend the investigation to the clays which were deposited near the margin of the lake, when the Winnipeg beds have been investigated in complete detail.

The most complete sections that have been available to date are the sections exposed in the foundation work for the municipal Standby Plant for Winnipeg, at the east end of Rupert Street, approximately 150 yards west from the west bank of the Red river, and the exposure on the Red river, on the east bank, immediately south of the C.P.R. bridge at Kildonan Park. These sections are given in detail in Figures 1 and 2. The descriptions of the sections are as follows:—

Section at Standby Plant, Rupert Street, Winnipeg. (Fig. 1)

Distance from Surface	Thickness	
2′ 8″	2′ 8″	Soil
5′ 2″	2′ 6″	Sand, in undulating, interrupted beds
7′ 8″	2′ 6″	Dark grey clay, finely bedded
8′ 4″	8″	Light yellowish clay, somewhat sandy
10′ 4″	2′ 0″	Dark grey clay, with fine and very perfect lamination.

Section on East Bank of Red River, 300 yards south of C.P.R. bridge at Kildonan Park. (Fig. 2)

Distance from Surface	Thickness	
3′ 9½″	3′ 9½″	Soil
4′ 4½″	7″	Marly beds
7′ 5½″	3′ 1″	Sand, irregularly bedded
8′ 6½″	1′ 1″	Dark grey clay, breaking in cubes
10′ 1″	1′ 6½″	Dark grey clay, finely bedded
10′ 9″	8″	Light yellowish clay, somewhat sandy
19′ 0″	8″ 3″	Dark grey clay, finely laminated

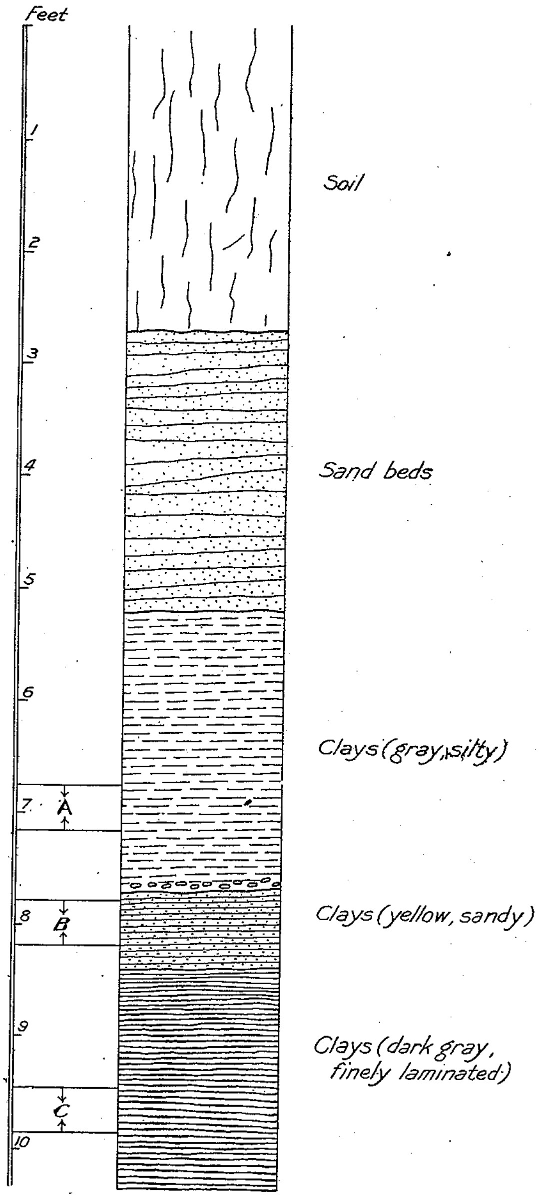

Fig. 1. Section at Standby Plant, Rupert Street, Winnipeg, Man.

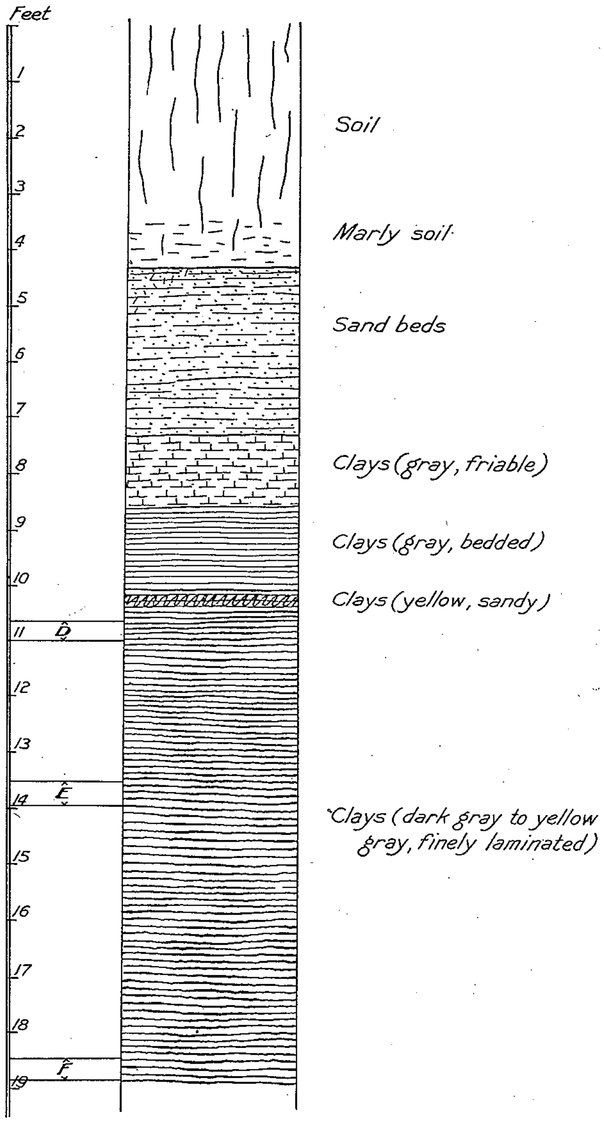

Fig. 2. Section, Right Bank, Red River, above Kildonan Park railway bridge, Winnipeg, Man.

In neither case was the section complete, the lower beds continuing beneath the exposed cut.

Sections were taken at other places in or in the outskirts of the city, from Fort Garry in the south to River Heights in the west. The soil varies from 2 to 4½ feet in thickness. The underlying sandy beds, usually irregularly bedded, vary considerably in their clay content, and, indeed, at Riverview (near King George Isolation Hospital) and at Queenstown Street (River Heights) are clays rather than sands. In St. Boniface, this same horizon provides the clays for the brickmaking industry. The nature of the bedding of these sands, clayey sands or sandy clays as the case may be, would indicate that they have been laid down by river action, and are later than, and not connected with, the Lake Agassiz stage. The Red river, or its late Pleistocene predecessor was apparently at this stage a shallow, rapid, sand-carrying stream which periodically overflowed its banks and deposited sand or silt as the occasion offered. Below these sand beds lie the clays which were undoubtedly lake deposited, and with them we are more immediately concerned.

The lake clays, in so far as they are exposed, consist of two series of finely laminated beds separated by a wellmarked, but thin, sandy bed. The upper series is between 2 feet and 3 feet thick, has less perfect lamination than the lower series, is more definitely silty, and tends to break, on drying, with definite cubical parting. The lower series is very perfectly laminated, very uniform throughout the whole section thus far obtained, and is built of laminae of almost leaf-like thinness. Separating the two series is a bed to which considerable interest is attached. It occurs in the Winnipeg area at a depth of from 8½ to 12 feet from the surface, varies in thickness from 4 inches to 8 inches, is uniformly pale yellow in color, has a high percentage of uncombined silica in the form of sand grains, and in the section south of the Kildonan Park bridge shows distinct cross bedding, with the dip of beds to the north. There was evidently a period of shallowing of the lake to the extent that, even in the deep Winnipeg basin, the lake had been replaced by a rapid, north-flowing river, which in turn gave place to a lake in which the upper clays were precipitated. Further evidence of the shallowing is noted in the Standby Plant section, where at distances 3 inches above the top of the yellow sandy bed, and 2 inches and 4 inches below the bottom of the same bed, very thin bands of gravel occur. The pebbles are of limestone and granite, and are the only materials of coarse grain in the whole section. W. A. Johnston[1], in his investigations in the Whitemouth Lake area, had noted this yellow bed, both on the G.W.W.D. line east of Winnipeg, and in the Red river valley, and had interpreted it as representing a shallowing of Lake Agassiz, an outlet having probably been temporarily found through the northern ice-sheet. The elevation of the erosion surface in the Greater Winnipeg Water District Railway section, as determined by Johnston is 1075 feet. In the Winnipeg sections it is 740 feet. Even when allowance is made for differential uplift since that time, the figures quoted indicate a lowering of the waters of the lake through at least 300 feet of vertical depth by a temporary opening to the north.

THE COLLOIDAL REACTION OF THE CLAYS

Preliminary to the study of the laminae of which the clay beds are composed, an investigation was made of the nature of the clay beds as a whole, by way of a comparison of the upper clay beds, the yellow bed, and the lower clay beds. An important practical feature to the study lay in the fact the Winnipeg builders found the yellow clay bed to be unsafe, and invariably place their foundations, for buildings of any considerable weight, below this bed. The study might be classified as (a) chemical, (b) colloidal, (c) mechanical. The chemical and colloidal studies are reported on in the present communication. The mechanical analysis, by the aid of the super-centrifuge, will be dealt with in a later paper.

Chemical Analysis

The samples of clay used for analysis were taken from the fresh excavations at the Standby Plant, Rupert Street, Winnipeg. Three analyses were made. The first (A) was of a typical five inch section of the gray silty clays; the second (B) was of a typical five inch section of the yellow sandy clays and the third (C) was of a typical five inch section of the dark gray finely laminated clays. The positions of the above sections were established by exact measurements; the first was 6 feet 9 inches to 7 feet 2 inches, the second 7 feet 10 inches to 8 feet 3 inches and the third 9 feet 5½ inches to 9 feet 10½ inches from the surface. As a result, an analysis of the yellow clay and a characteristic section above and below it were obtained. Great care was taken in cutting a uniform sample of each of the sections chosen.

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[1] Memoir 128 Geol. Surv. Can. 1921, p. 31.

Schloesing, Th. The Constitution of the Clays. Compt. Rend. Vol. 79, 1874, pp. 376-380.

The samples were carefully levigated in an agate mortar. Then they were well mixed, placed in the electric oven and dried at a temperature of 110° centigrade to remove the moisture. After drying, the samples were preserved in a desiccator.

The system of analysis used was that prescribed by W. F. Hildebrande in "The Analysis of Silicate and Carbonate Rocks," Bulletin 422, United States Geological Survey.

Table of Analysis

	A	B	C
Silica	56.02	58.63	55.48
Alumina	20.53	9.12	20.37
Iron Oxides	5.35	8.42	5.54
Magnesia	3.81	3.62	3.29
Lime	2.75	6.41	4.95
Sodium Oxide	.80	1.60	.82
Potassium Oxide	2.22	2.85	1.86
Ignition	9.02	9.00	8.77
	100.50	99.53	100.08

In examining these analyses it is seen that in general the compositions of (A) and (C) are somewhat similar; (B) however differs widely. This can partly be explained, for of the total amount of silica in (B) a large part, almost half of it, is free sand. If this is taken into account then (B) also is somewhat similar to (A) and (C).

The high percentage of magnesia and lime indicates that practically no leaching has taken place since the clays were deposited.

The excess of potassium over sodium in each analysis may be due to the greater ease with which potassium is absorbed by colloidal substances.

Colloidal Analysis

That clays contain colloids has been known for a considerable time. In 1874 a French ceramic chemist, Th. Schloesing[1] isolated the colloidal matter in clay, and showed that the amount of colloidal material in the best clays was small, rarely exceeding 1.5 per cent. He also was the first to suggest the idea that in controlling the plasticity of clays, it was a question of controlling the colloids. Little notice was taken of this work until 1896, when Rohland[2] made further investigations along this line and suggested that the power of absorbing a definite amount of water is due to the colloids in the clay,

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[2] Rohland, P. Die Tone.

and that as soon as the clay has absorbed a sufficient amount of water to convert its colloids into the form of a colloidal sol its ability to absorb water reaches a saturation point and ceases, this being proportional to the colloids present, and roughly, to the plasticity. According to Pearce and Miller[3], Keppler also found that the hygroscopicity of clays varied as the plasticity. Cushman[4] and Ashley[5] substantiated, to a certain degree, the theory of Schloesing, Ashley referring the plasticity to the gel structure of the clays themselves.

While most students of ceramics are in favor of the colloid theory for plasticity, others, for example Grout[6], consider plasticity to be due to molecular attraction and that colloids only play a modifying part. But nearly all agree that since the properties of colloids are primarily surface properties, any method which would determine the extent of surface development may be considered a measurement of the colloid content. This, however, is not of necessity a measure of the plasticity, for plasticity may depend to a certain extent on the result of several forces, some of which may not yet be recognized.

In studying the colloidality of Lake Agassiz clays no attempt was made to determine the absolute amount of colloids in each stratum; but the values obtained should give a correct estimate of the relative quantity of colloids in each section chosen.

Two methods were used for determining the relative surface development; (a) the adsorption of sodium carbonate by the clay, and (b) the hygroscopicity of the clay.

The samples for these measurements were taken from the Standby Plant and Kildonan Park sections in such an order that the Kildonan Park samples should be a continuation at depth of the Standby Plant samples. The first three (A), (B) and (C), which were similar to those used in the analysis, were taken from the Standby Plant section; while the last three (D), (E) and (F) were obtained from the Kildonan Park Section. The respective distances from the surface of the six samples chosen were (A) 6 feet 9 inches to 7 feet 2 inches, (B) 7 feet 9 inches to 8 feet 2 inches, (C) 9 feet 5½ inches to 9 feet 10½ inches, (D) 10 feet 7 inches to 11 feet, (E) 13 feet 6 inches to 13 feet 11 inches and (F) 18 feet 5 inches to 18 feet 10 inches. Sample (D) from the Kildonan Park section, was so chosen that it would very

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[3] Pearce, J. N. and Miller, L.B., Jour. of Phy. Chem., Vol. 26, No. 1, 1922, p. 17.

[4] Cushman, A. S. U.S. Dept. of Agr. Bur. Chem. Bull. 83.

[5] Ashley, H. E. The Colloidal Matter of Clay and its Measurement. U.S. Geol. Survey. Bull. 388, 1909.

[6] Grout, F. F. Clays and Shales of Minnesota, U.S. Geol. Survey, Bull. 678, p. 30, 1919.

closely resemble sample (C) of the Standby Plant section. For each sample a uniform five inch section was obtained.

Preparation of the samples:—About 50 grams of each sample were shaken up with water, the lumps being broken up by gently rubbing with the fingers. The clay suspension was then stirred vigorously for some time and allowed to stand until sedimentation became complete. The supernatant liquid was removed as completely as possible and part of the clay dried at room temperature, 23° centigrade and the remainder at a temperature of 110° centigrade in an electric oven. The dried material was carefully reduced to a fine powder, well mixed, and placed in a desiccator to prevent absorption of moisture from the atmosphere.

The adsorption of sodium carbonate by the clay

Holmes[7] states that according to Bleininger, "Plasticity is sometimes measured by letting a known weight of clay stand in a normal solution of sodium carbonate, then determining the amount adsorbed by the decrease in the strength of the solution. The amount of sodium carbonate adsorbed is supposed to be proportional to the colloids, which colloids are supposed to be the seat and source of plasticity."

Procedure:—Duplicate samples of each of the clays which had been dried at 110° centigrade, were accurately weighed out and placed in 500 cubic centimeter Eilenmeyer flasks. To each sample was added 100 cubic centimeters of a standardized normal sodium carbonate solution. At the end of 112 hours 25 cubic centimeters of the sodium carbonate solution were withdrawn from each flask by means of a pipette and titrated against a known solution of hydrochloric acid, which had been standardized to the sodium carbonate solution. The decrease in the strength of the sodium carbonate solution represented the amount of sodium carbonate adsorbed by the clay. The percentage adsorbed was then calculated. The values obtained are tabulated in Table I.

A survey of the data in this table shows that with the exception of section (B) the amount of sodium carbonate adsorbed increases with depth and since the amount of sodium carbonate is proportional to the colloids present, then the colloidal content increases with depth. Section (B) which was taken from the yellow sandy bed contains less colloidal material than any of the other sections.

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[7] Holmes, H. M. Laboratory Manual of Colloidal Chemistry, p. 105, 1922.

TABLE 1.

Comparison of the Adsorptive Power of the Various Clay Sections, for Sodium Carbonate

Sections	From surface	Percentage of Sodium Carbonate adsorbed
A	6′ 9″ to 7′ 2″	1.51
B	7′ 9″ to 8′ 2″	1.38
C	9′ 5½″ to 9′ 10½″	1.99
D	10′ 7″ to 11′ 0″	1.94
E	13′ 6″ to 13′ 11″	2.16
F	18′ 5″ to 18′ 10″	2.35

The hygroscopicity of the Clays

This depends upon the power of clays to absorb moisture from a moist atmosphere. As has been stated previously, the amount of water absorbed varies directly as the colloidal content. The method used was adapted from Patten and Gallagher.[8]

Two parallel series of the clay sections were taken. In one series the clays used were those which had been dried at room temperature, 23° centigrade, and in the other, samples of the same clays were used, but in this case they were dried at a temperature of 110° centigrade in the electric oven.

Procedure:—Wet sponges were placed in the bottom of desiccators to saturate the atmosphere with moisture. Ten gram samples of each of the prepared clays were placed in shallow dishes and the dishes and contents were put in the desiccators. At first to find the amount of water absorbed, weighings were made every few hours, but towards the end weighings were made only every other day. These weighings were continued until the change in weight of the samples between each successive reading became negligibly small. The desiccators were kept as nearly as possible at a temperature of 23° centigrade.

The time in hours and the percentage of water absorbed in each case were plotted on graphs, the ordinates representing the length of time the clay remained in contact with the moist atmosphere, the abscissae representing the percentages of water absorbed. The maximum value of the abscissae of each curve gives the total percentage of water that each sample would absorb.

In examining the graphs it is seen that all the curves are of a similar nature. At first the rate of absorption is very rapid, consider-

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[8] Patten and Gallagher, Absorption of Vapors and Gases by Soils, Bur. of Soils Bull. 5.

ably over fifty per cent. of the total water taken up being absorbed within the first 40 hours which is only about one-ninth of the total time required for the curves to reach their asymptotic limits. The curves also show that approximately the same length of time is required for a maximum value to be reached whether the clays were dried at 110° centigrade or at 23° centigrade which shows that the rate of absorption of those dried at 110° centigrade has increased an appreciable amount over that of the same clays when dried at 23° centigrade. As each curve represents the hygroscopicity of different clay sections taken at descending depths, it is obvious that descending

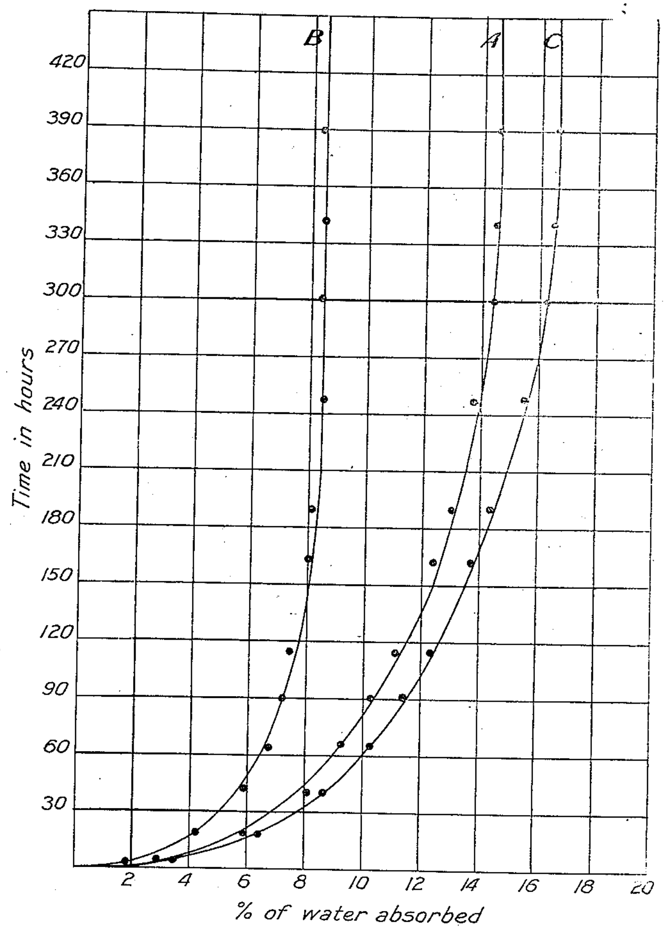

Fig. 3. Hygroscopicity curves of clay samples which have been dried at room temperature.

from (A) to (F) and omitting (B) the rate of absorption for corresponding points on each curve increases. Thus it is seen that the rate of absorption at any instant depends both on the colloids, and on the amount of moisture which the clays already contain; also the maximum rate of absorption takes place at the exact instant the dried clay is brought in contact with the moist atmosphere and from that moment until the final value is reached the rate gradually decreases.

Section (B), which is of the yellow sandy band, has much lower rates of absorption than the corresponding rates of the other sections, and it also takes it far less time to absorb its maximum amount of water.

The maximum amount of water absorbed in each case is indicated in the following table:

TABLE 2

Hygroscopicity of Clays which have been dried at Room Temperature

Section	From surface	Percentage of water absorbed
A	6′ 9″ to 7′ 2″	14.6
B	7′ 9″ to 8′ 2″	8.6
C	9′ 5½″ to 9′ 10½″	16.6
D	10′ 7″ to 11′ 00″	16.65
E	13′ 6″ to 13′ 11″	17.2
F	18′ 5″ to 18′ 10″	19.3

TABLE 3

Hygroscopicity of Clays which have been dried at 110° centigrade.

Section	From surface	Percentage of water absorbed
A	6′ 9″ to 7′ 2″	19.4
B	7′ 9″ to 8′ 2″	11.7
C	9′ 5½″ to 9′ 10½″	21.4
D	10′ 7″ to 11′ 00″	21.0
E	13′ 6″ to 13′ 11″	21.5
F	18′ 5″ to 18′ 10″	24.4

Tables 2 and 3 confirm very satisfactorily the results obtained in Table 1, namely that the colloidality of these clays increases with depth and that section (B) contains the least colloidal material.

Investigations carried on by Pearce and Miller[9] show that in clays derived from glacial till, the colloidal content decreases with depth. They also prove that the colloids in these clays have been

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[9] Pearce, J. N. and Miller, L.B. Jour. of Phy. Chem., Vol. 26, No. 1, 1923.

formed by leaching and weathering. The colloidal content of the Lake Agassiz clays thus far examined did not decrease but increased with depth; moreover, as was pointed out in the discussion of the analysis, leaching could not have gone on to any great extent. These colloids were not formed by leaching but were deposited at the time the clays were laid down. Whether the colloidal content has increased or decreased since deposition is not known.

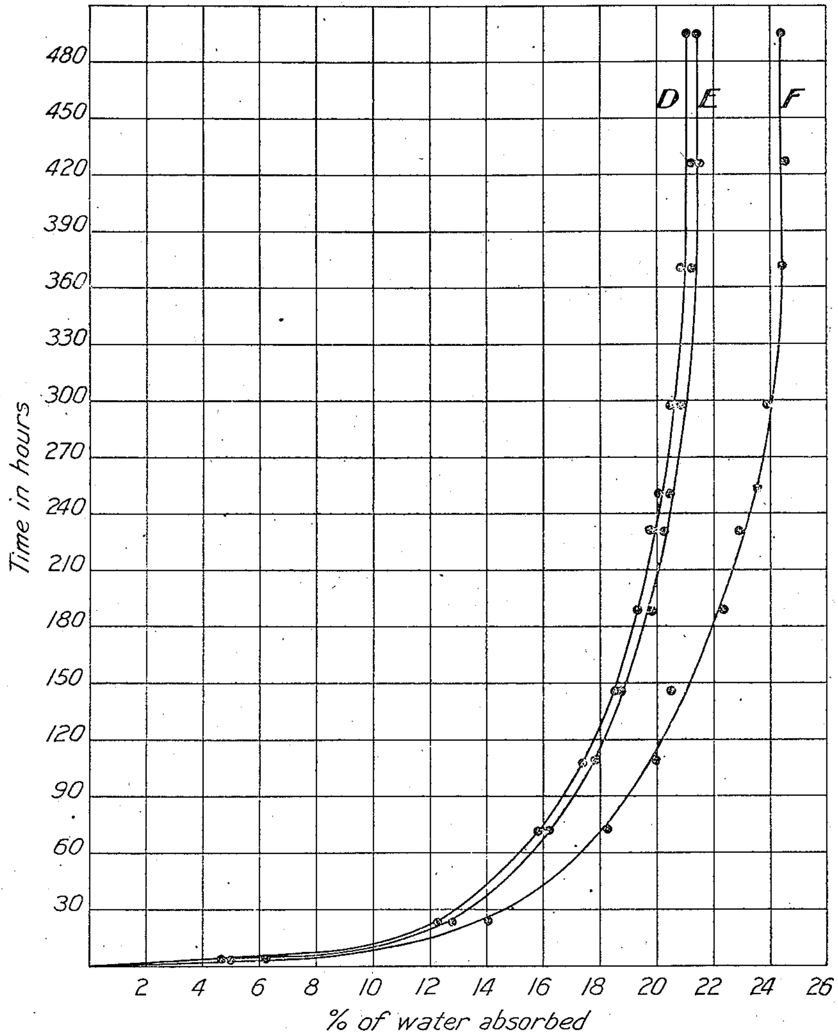

Fig. 4. Hygroscopicity curves of clay samples which have beed dried at room temperature.

A sample of each of the clays which had been dried at room temperature was heated in the electric oven for 24 hours at 110° centigrade.

The percentage of water lost in each case is given in the following table.

TABLE 4

Percentage of Water Contained in Clays which have been dried at 110° centigrade

Sections	From surface	Percentage of water in clays
A	6′ 9″ to 7′ 2″	4.65
B	7′ 9″ to 8′ 2″	3.2
C	9′ 5½″ to 9′ 10½″	4.7
D	10′ 7″ to 11′ 00″	4.55
E	13′ 6″ to 13′ 11″	4.50
F	18′ 5″ to 18′ 10″	5.00

Below is given a summary of the results obtained in Tables Two, Three and Four.

TABLE 5

Summary of Tables Two, Three and Four

Sections	From surface	Table 2	Table 4	Tables 2 and 4	Table 3
A	6′ 9″ to 7′ 2″	14.60	4.65	19.25	19.40
B	7′ 9″ to 8′ 2″	8.60	3.20	11.80	11.70
C	9′ 5½″ to 9′ 10½″	16.60	4.70	21.30	21.40
D	10′ 7″ to 11′ 00″	16.65	4.55	21.20	21.00
E	13′ 6″ to 13′ 11″	17.20	4.50	21.70	21.50
F	18′ 5″ to 18′ 10″	19.30	5.00	24.30	24.40

In the above summary it is seen that if there are added together the results obtained in Table Two (Hygroscopicity of clays which have been dried at room temperature) and those obtained in Table Four (Percentage of water contained by the same clays which have been dried at 110° centigrade) the results tabulated in the column headed "Tables 2 and 4" will be obtained. On comparing these values with those obtained in Table 3 (Hygroscopicity of clays which have been dried at 110° centigrade) it is obvious that practically the same values have been obtained. The slight differences are likely due to experimental error.

In summation, the relative colloidal content has been obtained in two different manners; first, by heating the clay at 110° centigrade until all the uncombined water was driven off and then seeing how much moisture the clay would absorb on exposure to a moist atmosphere, and second, by drying the clays at room temperature, exposing them to a moist atmosphere and calculating the amount of moisture contained in another sample of the same clay which was dried at 110° centigrade; and similar results obtained. This shows that

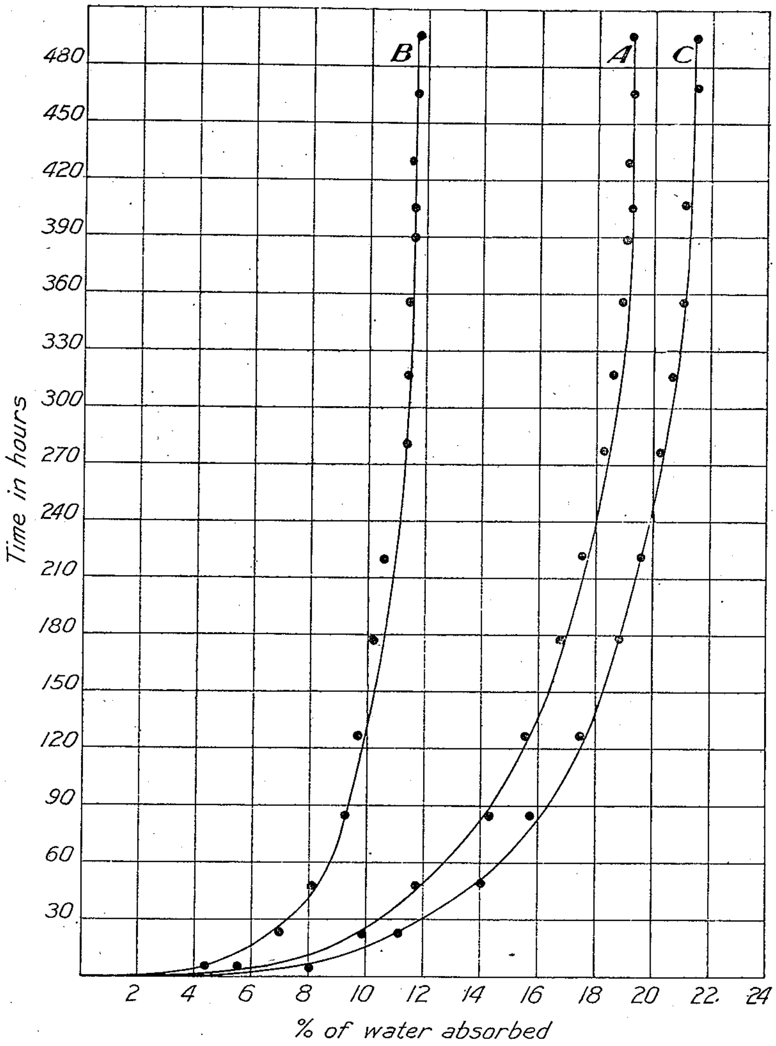

Fig. 5. Hygroscopicity curves of clay samples which have been dried at a temperature of 110°c.

heating to 110° centigrade has no appreciable effect on the colloids in the clay.

Total Water Capacity

The total water capacity, according to Pearce and Miller[10] is the number of grams of water which when added to one gram of clay is just sufficient to cause it to flow, or in other words as is pointed out by Cameron[11] it is the sum of the hygroscopic water capacity and the interstitial water capacity which he calls the free water capacity.

Using the method prescribed by Pearce and Miller, the total water capacities of the six sections used in the hygroscopicity tests were determined.

Procedure:—Ten gram samples of each of the clays were placed in tared bottles. The samples were then heated in the electric oven at 110° centigrade until constant in weight. Distilled water was then added drop by drop from a burette with constant stirring, until a furrow made in the clay with a glass rod was immediately filled with the clay and water. Finally the bottles were dried, placed in the balance case for a few minutes and weighed. Part of the water was allowed to evaporate from each of the bottles and the above process repeated until the readings were almost constant, not differing by more than ±.05 grams.

The total water capacities expressed in percentages by weight of water taken up by the dried clay is given in the following table.

TABLE 6

The total Water Capacities of the Clay Sections

Sections	From surface	Total Water Capacity
A	6′ 9″ to 7′ 2″	128.1
B	7′ 9″ to 8′ 2″	86.1
C	9′ 5½″ to 9′ 10½″	133.7
D	10′ 7″ to 11′ 00″	132.5
E	13′ 6″ to 13′ 11″	135.7
F	18′ 5″ to 18′ 10″	154.1

As is seen from the above table the total water capacity of each of the sections is enormous. In every case with the exception of (B) it is over 100 per cent. by weight of the dried sample. Another

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[10] Pearce and Miller. Colloidal Properties of Pleistocene Clays. Jour. of Phy. Chem., Vol. 36, No. 1, 1922.

[11] Jour. Phy. Chem., Vol. 14, 340, 1910.

very outstanding fact is that the total water capacity increases with depth. It is suggested that this increase with depth may be due to the gradual shallowing of Lake Agassiz, for when the lower clays were laid down the lake was of great size and extent, the part where Winnipeg now stands being under several hundred feet of water, and at a great distance from any of the inlets of the Lake; consequently only the very finest products of rock weathering were able to accumulate there and be deposited either colloidally or otherwise. As the lake gradually shallowed, material of a coarser type was able to accumulate and be deposited. Thus since the total water capacity depends, first, upon the interstitial space between the particles and second, upon the surface effects of the particles themselves, it is apparent that the lower clays, being composed of the finest particles, would have both the greatest interstitial space and the largest surface effect, and that due to the shallowing of the lake these two factors would gradually diminish, which would result, ascending from bottom to top, in a gradual decrease in the total water capacity of the clays.

It should be possible, by means of a super-centrifuge to obtain definite results as to the variation with depth in the size of the clay particles.

Free Water Capacity

The free water capacity is the difference between the total water capacity and the hygroscopic water capacity, or as defined by Cameron[12] it is the water in the soil which is not absorbed by the soil particles. Thus, as was mentioned previously, it is a measure of the interstitial space of the clay.

In Table 7 the free water capacities expressed in percentages by weight of the dried sections are given.

The free water capacity, as well as the total and hygroscopic water capacities, increases with depth.

TABLE 7

Free Water Capacities of the Clay Sections

Sections	From surface	Free Water Capacity
A	6′ 9″ to 7′ 2″	108.7
B	7′ 9″ to 8′ 2″	74.4
C	9′ 5½″ to 9′ 10½″	112.3
D	10′ 7″ to 11′ 00″	111.5
E	13′ 6″ to 13′ 11″	114.2
F	18′ 5″ to 18′ 10″	129.7

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[12] Jour. of Phys. Chem., Vol. 14, 340, 1910.

If, as is believed, the slipping of the foundations of the older buildings in the City is due to the yellow sandy band which is represented by section (B), it is quite possible that in some way not yet explained the great differences in the free water and total water capacities between the yellow band and the sections above and below may have caused the slipping.

Additional investigations will be carried out to find the effect of higher temperature on the colloidal content of the clays, and to obtain accurate data on the variation in the size of grains of the dry particles with depth. It will then be possible to undertake the more

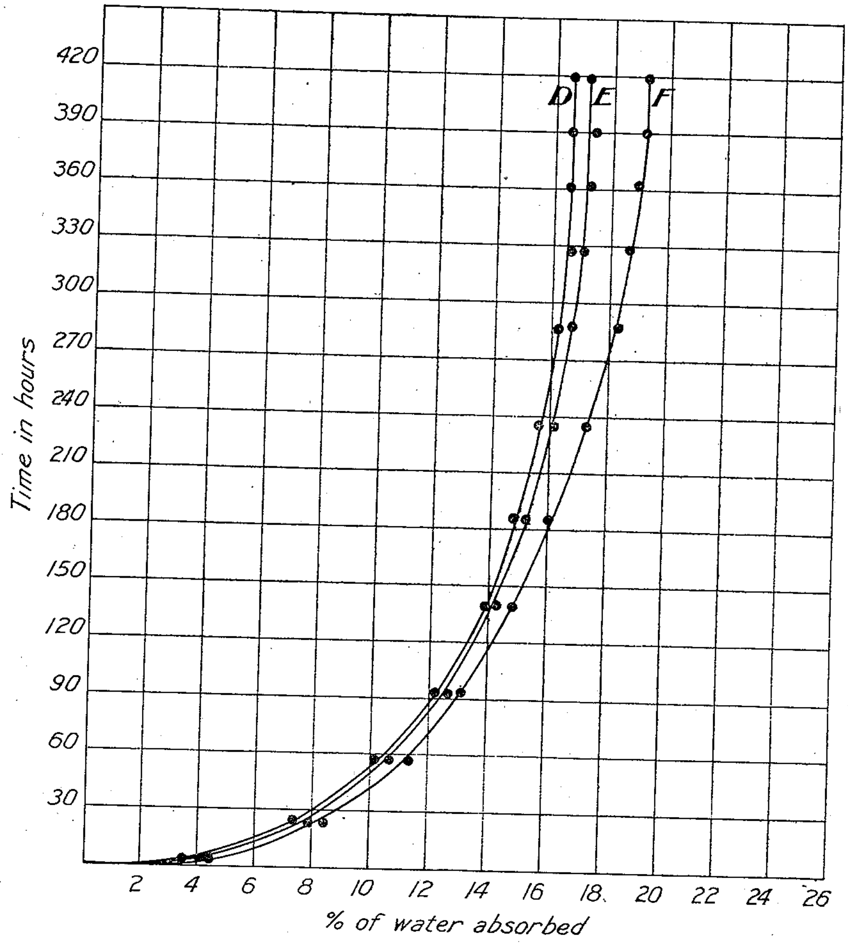

Fig. 6. Hygroscopicity curves of clay samples which have been dried at a temperature of 110° c.

minute analysis of the seasonal layers and the value of the factor of colloidal deposition under glacial lake conditions.

SEASONAL DEPOSITION

Since the publication of Baron de Geer's work on the seasonal banding of the post-glacial clays of Sweden, and the value of the banding in estimating the duration of post-glacial time, some interest has been taken in the investigation of seasonal banding in the lake clays of other areas. Sayles[13] has interpreted the banding of the clays of the Connecticut valley as representing the seasonal banding of clays deposited in a glacial lake, and has suggested a similar explanation for the bandings of the Squantum tillite of Boston.

Berkey[14] has explained the laminated interglacial clays of Grantsburg, Wisconsin, as illustrating seasonal accumulation. Johnston[15] has noted the seasonal layers in the fresh water beds at the bottom of Lake Louise, a modern glacial lake, the banding being caused by the almost immediate settling of the coarser particles and the gradual silting of the finer material in a water where the electrolytic content was not sufficient to throw down the finer sediment with the coarser material. The seasonal band consists of a coarse layer below, grading into a finer layer above, the total thickness being one-fifth to one-sixth of an inch in the deeper parts of the lake, whose maximum length is 1¼ miles. Kindle[16] has carried out experimental work on the settling of clay-sand materials in fresh and salt water, and has reached the conclusion that a sharply differentiated succession of beds, such as sandstone and shale, is characteristic of saltwater deposition, while the undifferentiated sandy shales are representative of freshwater deposition. For example, if sand enters a freshwater lake in which finely divided clay had previously been depositing, the sand will fall to the bottom before the sedimentation of the clay is complete: if, however, the basin is marine, the clay will have been completely deposited before the sand enters the basin. Diastrophic changes, according to Kindle, are more definitely punctuated in the marine sediments; seasonal changes according to Johnston, are more clearly seen in freshwater sediments. These statements involve no contradiction. When the sediments are continuous in type from season to season, as when muddy rivers carry their load to a lake, the sifting process takes place from summer to winter in the fresh water

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[13] Sayles, R. W. Mem. Mus. Comp. Zool. Harvard, 47, 1, 1919.

[14] Berkey, C. P. Journ. Geol., 13, 35, 1905.

[15] Johnston, W. A. Amer. Journ. Sc., IV, p. 376, 1922.

[16] E. M. Kindle. Bull. Geol. Soc. Am., 28, 1917, p. 916.

bains, and seasonal layers are formed. In order, however, to differentiate clearly between that phase of sedimentation, and a succeeding arenaceous phase, complete settling of the clay must have taken place before the sandy material was introduced. That condition is best fulfilled in salt water settling basins.

The Winnipeg glacial clays were deposited in deep water many miles from a shoreline of the glacial lake. It was to be expected, therefore, that the seasonal layers—if such occurred—would be abnormally thin. An examination of the clay immediately below the yellow bed, at a place where the bedding is most distinct, proved this to be the case. A reproduction is given in Fig. 7 of a section 1 inch in thickness at a depth of 9 feet 2 inches in the Standby Plant excavation on Rupert Street, Winnipeg (see section in Fig. 1). By the aid of a lens, 49 layers were counted in the thickness of 1 inch, and it cannot be positively stated that all the layers were identified. This was typical of the lower clays, to the bottom of the section obtained at the Standby Plant in Winnipeg, or on the Red river opposite Kildonan Park. These clays may be described as made up

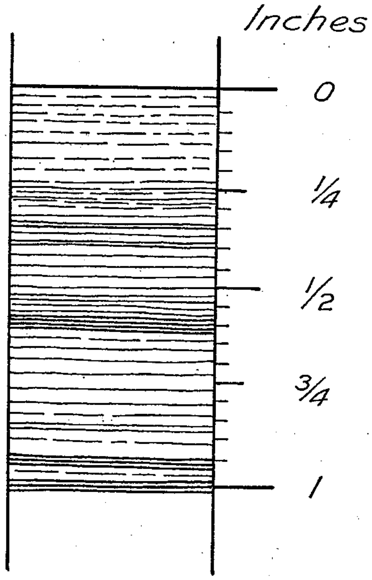


Fig. 7. Drawing of section, 1 inch thick, to illustrate planes of sedimentation of Lake Agassiz clays. Standby Plant, Rupert St., Winnipeg. 9 feet 2 inches below surface level.

of extremely thin laminae or bands, of an average thickness varying from 1-50th to 1-40th of an inch, and with no great variation in thickness from those limits. There are layers which stand out more distinctly than the others, some of which may reach a thickness of 1-10th of an inch, but such are exceptional. The thicker layers are characterised also by their lighter colour, significant of a higher percentage of arenaceous material. They are seen in fair definition in Plate I. The inch section shown in Fig. 7 is the third inch from the top of the section photographed in Plate I.

The variations from bottom to top of the individual layers will be dealt with in a further communication on the mechanical composition of the clays.

SUMMARY

The results obtained in the investigations on the Lake Agassiz clays are given below.

The sections in the Winnipeg area consist of soil (approx. 4 feet), sand to sandy clay (approx. 3 feet), lake clay, friable and bedded (approx. 3 feet), yellow sandy clay (approx. 6 in.), fine bedded dark grey clays (9 feet +).

The greatest variation occurs in the upper sandy clay, which is probably river deposited.

The lower yellow clay shows very little variation. It was laid down in a north-flowing river during a temporary emptying of Lake Agassiz.

The upper and lower bedded clays are true lake deposits, laid down at great depths in the glacial lake.

There has been practically no leaching of the clays since deposition.

The yellow sandy clays represented by section (B) contain less colloidal material than either the gray, silty clays above it or the dark gray, finely laminated clays below it.

The colloidal content of the clays investigated, with the exception of section (B) mentioned above, increases with depth.

The colloids in the clays were not formed by leaching but were deposited at the time the clays were laid down.

Temperatures up to 110° centigrade have no appreciable effect on the colloids in the clay.

The rate of absorption of moisture by the clays from a moist atmosphere depends upon two factors, namely, the amount of colloids in the clays, and the quantity of moisture the clays already contain. The maximum rate of absorption takes place at the exact instant the dried clay is brought into contact with the moist atmosphere and from that moment until the final value is reached the rate gradually decreases.

The yellow sandy band has the least "total" and "free" water capacity.

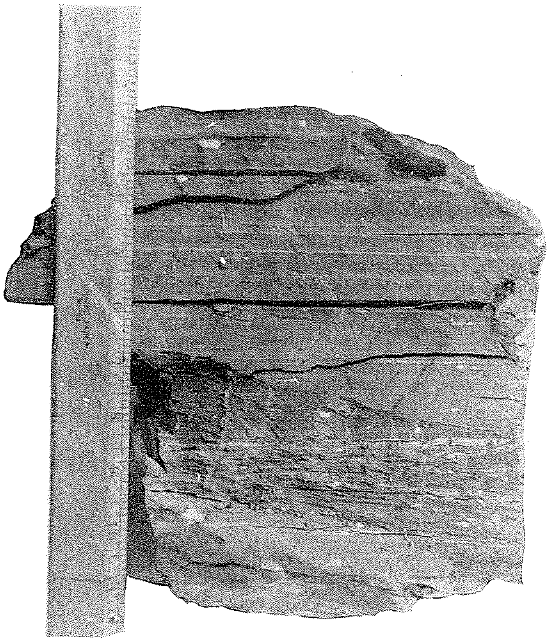
The "total" and "free" water capacity in all the clays with the exception of the yellow sandy band increases with depth.

The colloidal factor is of minor importance in the slipping of the yellow band (B) beneath heavy buildings. The cause of slipping has not as yet been determined.

The lake clays show very definite seasonal bandings, 1-40th to 1-50th of an inch in thickness. Exceptional bands, more sandy in nature, reach a maximum thickness of 1-10th of an inch. The bands represent the finest portions of the clays, deposited at great depths in the centre of the lake.

The authors take this opportunity of expressing their appreciation to the Honorary Advisory Council for Scientific and Industrial Research for the assistance rendered in the progress of their research. The junior author holds a bursary from the Council, and the results of the investigations to date are here presented by permission of the Council.

PLATE I



To illustrate seasonal banding in Lake Agassiz Clays.

THE CLAYS OF THE LAKE AGASSIZ BASIN

BY J.E. MAYNARD, B.A. B.Sc.

Presented in partial fulfillment of the
requirements for the Master of Science
Degree in the University of Manitoba.

M A Y 1925

THE CLAYS OF THE LAKE AGASSIZ BASIN
BY J. E. MAYNARD, B.A. B. Sc.

INTRODUCTION

Dr. Wallace and the writer, as indicated in a previous paper, carried on a preliminary investigation on the clays of the Lake Agassiz Basin, the study being confined principally to the chemical and colloidal character of the clays, with some work on sedimentation. The present paper deals also with chemical colloidal and mechanical properties of the clays, but in addition a little work has been done on the technological side and a chapter has been inserted on the Don River clays, in which a mechanical as well as a colloidal and chemical study have been made.

mThe chapter on chemical analyses is to some extent a repetition of that given in the paper by Dr. Wallace and myself, but this was thought necessary as three more analyses were made, which with those given in the first paper, give, with depth, a fairly accurate chemical knowledge of the complete clay section.

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1. Wallace, R.C. and Maynard, J.E. The Clays of the Lake Agassiz Basin. Trans. Roy. Soc. of Canada.Sec.IV.P.9.1924.

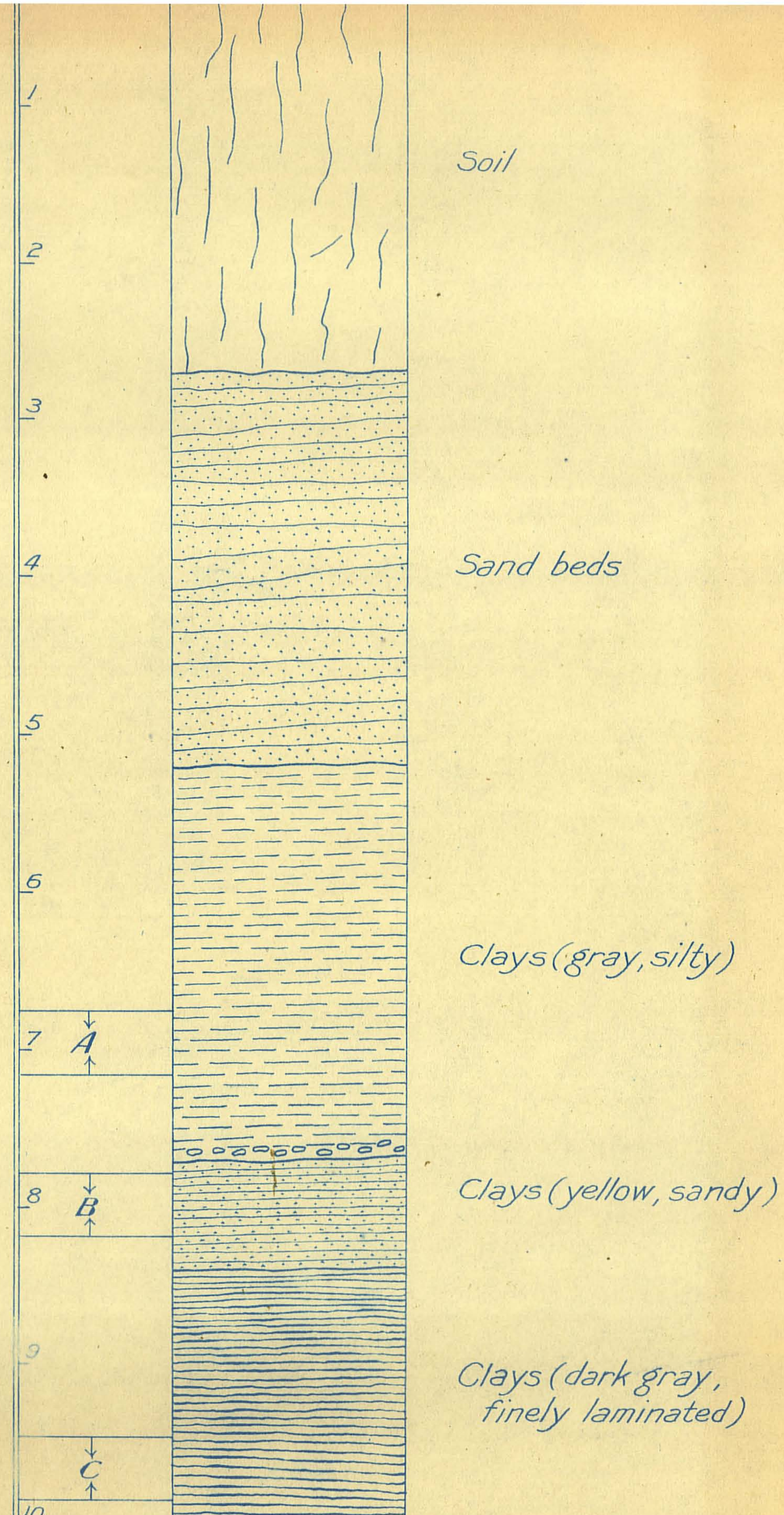


Figure 1. Section at Standby Plant

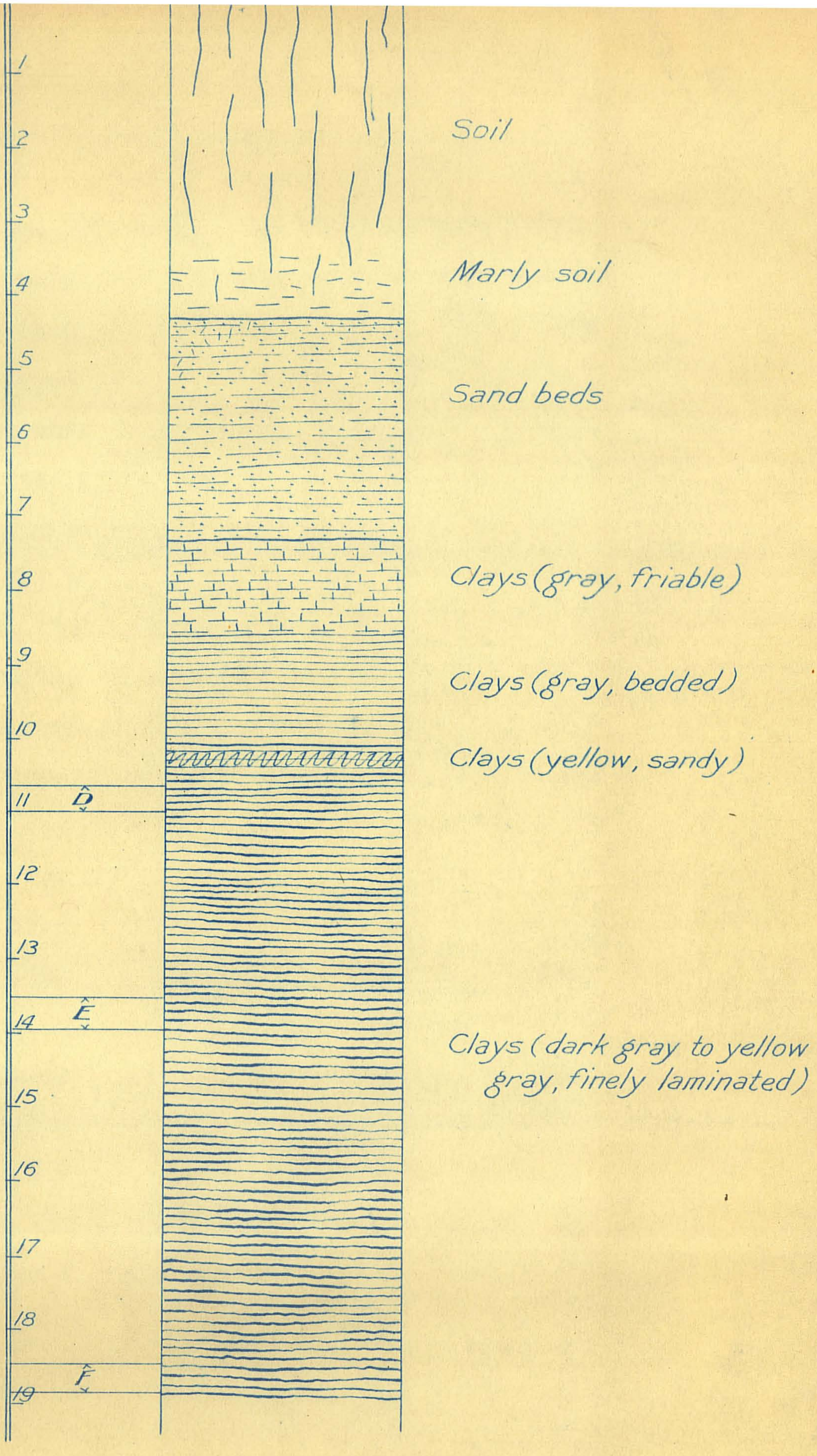


Figure 2. Section, right bank, Red River, above Kildonan Park railway bridge,

CHEMICAL ANALYSES

The samples of clay used for analyses were taken from the fresh excavations at the Standby Plant, Rupert Street, Winnipeg, and from the section which was obtained from the right bank of the Red River, just above the Kildonan Park Railway Bridge, Winnipeg. Six analyses were made; the first three being made from the samples which were obtained from the Standby Plant section and the second three from the samples obtained from the Kildonan Park section. The Kildonan Park samples were so chosen that they would be a continuation at depth of the Standby Plant samples. The first analysis (A) was of a typical five inch section of the gray silty clays; the second (B) was of a typical five inch section of the yellow sandy clays; the third (C) was of a typical five inch section of the dark gray finely laminated clays: (D), (E) and (F) are analyses of typical five inch sections of the dark gray finely laminated clays. The sample from which the analysis (D) was made was so chosen that it would be practically similar to the sample from which the analysis (C) was made, although the former was taken from the Kildonan Park Section, and the latter from the Standby Plant Section. The positions of the above samples, chosen for analyses, were established by exact measurements; the first was(measured from the surface) 6 feet 9 inches to 7 feet 2 inches; the second 7 feet 10 inches to 8 feet 3 inches; the third 9 feet 5½ inches to 9 feet 10½ inches; the fourth 10 feet 7 inches to 11 feet 0 inches; the fifth 13 feet 6 inches to 13 feet 11 inches, and the sixth 18 feet 5 inches to 18 feet 10 inches from the surface. As a result, an analysis of the yellow clay, one of the gray silty clays above it, and three of the dark gray finely laminated clays below it have been obtained. Great care was taken in cutting a uniform sample of each of the sections chosen.

The samples were carefully levigated in an agate mortar. Then they were well mixed, placed in the electric oven and dried at a temperature of 110° centigrade to remove the moisture. After drying, the samples were preserved in a desiccator.

The system of analysis used was that prescribed by W.F. Hildebrande in "The Analysis of Silicate and Carbonate Rocks", Bulletin 422, United States Geological Survey.

Table I

CHEMICAL ANALYSES

	A.	B.	C.	D.	E.	F.
Silica	56.02	58.63	55.48	55.62	53.56	52.44
Alumina	20.53	9.12	20.37	20.21	22.70	23.24
Iron Oxides	5.35	8.42	5.54	5.14	5.97	5.43
Magnesia	3.81	3.62	3.29	3.31	3.79	1.97
Lime	2.75	6.41	4.95	5.00	4.80	5.34
Sodium Oxide	.80	1.60	.82	.83	.99	1.02
Potassium Oxide	2.22	2.85	1.86	1.72	1.03	2.03
Ignition	9.02	9.00	8.77	8.83	7.99	9.00
	100.50	99.53	100.08	100.76	100.83	100.47

In examining these analyses it is seen that in general the composition of (A), (C), (D), (E) and (F) are somewhat similar; (B) however differs widely. This can be partly explained, for of the total amount of Silica in (B) a large part, almost half of it, is free sand. This sand is so fine however that the greater portion of it comes between the limits of what is defined as silt, that is the particles range in diameter from 0.005 millimeters to .05 millimeters.

The High percentage of Magnesia and Lime indicates that practically no leaching has taken place since the clays were deposited. The excess of potassium over sodium in each analysis may be due to the greater ease with which potassium is adsorbed by colloidal substances.

Iron Oxides, Magnesia, Lime, Soda, Potash and chemically combined water are known as the fluxing ingredients of the clay. Titanic acid acts as a flux at high temperatures.

The following table gives the percentages of fluxes that were determined in each analysis:

TABLE OF FLUXING INGREDIENTS

	A.	B.	C.	D.	E.	F.
Iron Oxides	5.35	8.42	5.54	5.14	5.97	5.43
Magnesia	3.81	3.62	3.29	3.31	3.79	1.97
Lime	2.75	6.41	4.95	5.00	4.80	5.34
Sodium Oxide	.80	1.60	.82	.83	.99	1.02
Potassium Oxide	2.22	2.85	1.86	1.72	1.03	2.03
	14.93	22.90	16.46	16.00	16.58	16.79

From the above table it is seen that the yellow band which is represented by (B) has the highest total percentage of fluxes, that the gray silty clays above the yellow band which are represented by (A) have the least, and that the dark gray finely laminated clays below the yellow band which are represented by (C), (D), (E), and (F) have an intermediate amount of fluxing ingredients which holds very constant with depth.

Owing to the high percentage of fluxes in all the clays analysed, the only technical use that might be made of these clays would be for the manufacture of common brick and even this would be doubtful as the chemical constitution of a clay only plays a small part, so that before a definite statement could be made, other tests such as plasticity, shrinkage, tensile, strength, etc., would have to be made.

COLLOIDAL

THE EFFECT OF TEMPERATURE ON THE COLLOIDS IN THE CLAY.

In looking over the available literature very little information could be found on the effect of temperature on colloids in clay. It is a well known fact that on heating to temperatures of 415 to 600 degrees centigrade all clays lose their plasticity and it cannot be restored (2), but as plasticity is only partially due to the colloids in the clay, it cannot be said that all the colloidal material has been destroyed on heating to the above temperatures (3).

Davis (4) claims that the water is held by the colloids in the clay with great force and that temperatures as high as 900 and 1000 degrees centigrade are required to drive off the last traces, and that a colloid which has been heated to this temperature loses its power to reabsorb moisture, that is, it cannot be changed again to the gel form.

Spence (5), working on the Bentonites of Alberta and British Columbia found that there was a marked decline in their colloidal distention properties as they were heated to different temperatures.

(2.) Knap, G.N. The Foundry Sands of Minnesota, Minnesota. Geological Survey Bull. 18, p. 77, 1923.

(3.) Grout, F.F. Clays and Shales of Minnesota, M. U.S.G.S. Bull. 678, p. 30, 1919.

(4.) Davis, R.O.E. Constituents of Soil Material as related to sedimentation. Report of committee on sedimentation, page 47, 1924.

(5.) Spence, H.S. Bentonites, Department of Mines, Canada, Bull. 626, p.16.

In the present investigations on the effect of temperature on the colloids in the different sections of the Lake Agassiz clays, the hygroscopicity method, which has already been described in detail, was used for determining the relative amounts of colloidin each sample after it had been heated to the required temperature. The samples of clay used were the same as those used in the hygroscopicity determinations and as a result the effect of low temperature, that is 23° centigrade and 110° degrees centigrade, on the colloids in the clays have already been determined. The effect of high temperatures on the colloids in the clays was obtained in a similar manner; the same samples as were used for the low temperature determinations being heated respectively to temperatures of 200, 400, 600, 800, and 1000 degrees centigrade and the hygroscopicity for each sample being determined after it was heated to the required temperature. The total percentage of water absorbed in each case is given in the following table:

TABLE 2.

Hygroscopicity of clays which have been heated to different temperatures.

Percentage of water absorbed at the following temperatures:

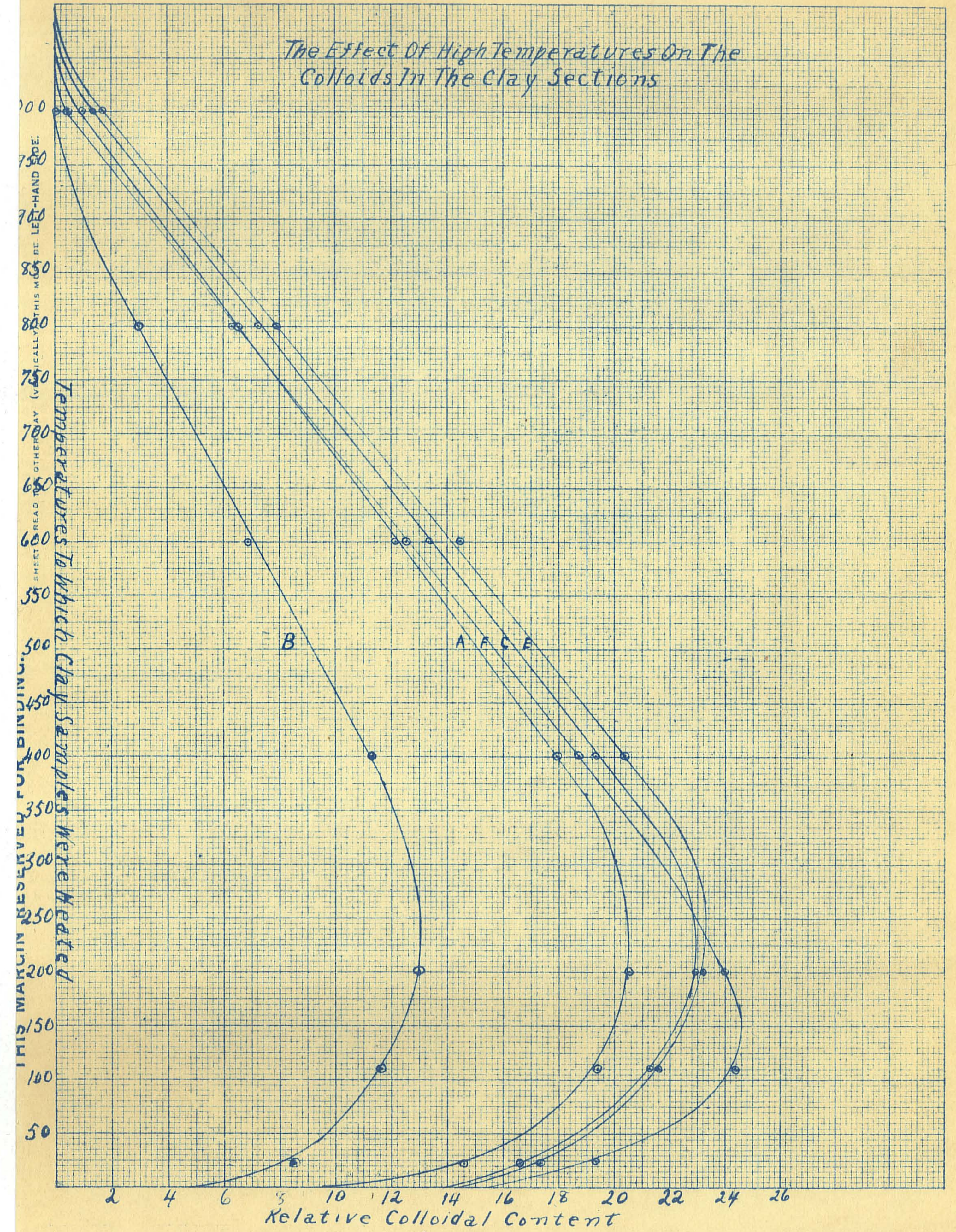
Section	From Surface	23°C.	110°C.	200°C.	400°C.	600°C.	800°C.	1000°C.
A	6'9" to 7'2"	14.60	19.40	20.50	17.90	12.15	6.53	0.95
B	7'9" to 8'2"	8.60	11.70	13.00	11.25	6.95	3.00	0.00
C	9'5½"to 9'10½"	16.60	21.40	23.00	19.24	13.30	7.25	1.40
D	10'7" to 11'00"	16.65	21.00	22.40	19.30	13.00	7.46	1.35
E	13'6" to 13'11"	17.20	21.50	23.10	20.32	14.50	7.92	1.72
F	18'5" to 18'10"	19.30	24.40	24.00	18.70	12.52	6.35	0.41

In following each of the actions in Table 2. through the range of temperatures to which it has been heated, that is, from 23 to 1000 degrees centigrade, it is seen that from 23 to 200 degrees centigrade, the total amount of water absorbed gradually increased and that from 200 to 1000 degrees the total amount of water absorbed gradually decreases. At present the only available reason for the increase in the total amount of water absorbed up to 200 degrees centigrade is that a temperature of at least 200 degrees centigrade is required to drive off all the water that was previously in the clay, although it may just be possible that heating to 200 degrees centigrade has increased the fineness of the grain of the clay, and as a result, the colloidal content has been increased. The gradual decrease in the total amount of water absorbed on heating from 200 to 1000 degress centigrade is due to some effect that the higher temperatures have on the colloids in the clay.

With the exception of section (B) the power of the different sections to absorb water is totally destroyed at a little over 1000 degrees centigrade, while the power of section (B) is destroyed at slightly under 1000 degrees centigrade.

The values obtained for each section in Table 2. with the exception of the values obtained for section (D), which were too closely related to those obtained from section (C) for they both are practically the same clay were plotted on a graph, (Fig.3), the ordinates representing the temperatures to which the clay samples were heated and the abscissae representing the total amount of water absorbed by each section after heating to that temperature.

In examining the curves in Fig. 3, it is seen that they all are of a similar nature. The total amount of water absorbed gradually increases to a maximum and then diminishes as the



The Effect Of High Temperatures On The Colloids In The Clay Sections

Fig 3

temperatures to which the clay samples were heated is increased.

Since the hygroscopicity is proportional to the amount of colloids present in the clay, it may be possible that, as the samples are heated to a higher temperature, part of the material, which is within the limits assigned to the colloidal specie, that is one micron or less, may aggregate and form particles which are above this limit. Sauramo (6) in studying the varve sediments of Southern Finland used the hygroscopicity method for determining the grain of the clays, so it is quite possible that the above suggestion is the correct one. Further work will have to be done with respect to the grain of the samples after they have been heated to the different temperatures before a definite statement can be made.

It may just be possible that the colloids in the clay gradually form a gel and that in the formation of this gel they absorb the water so that as the temperature is increased this ability to form a gel is gradually lost and finally, at a temperature of about 1000 degrees centigrade, this power is completely destroyed. That is the colloids have not been destroyed, but they have become irreversible.

The low hygroscopicity of (B) throughout the temperature range is probably due to this section containing less colloidal material. (F) shows a greater hygroscopicity at low temperature than either (A), (B), (C) or (E), while at high temperatures, with the exception of (B), it shows the least hygroscopicity, At present no explanation is available.

(6). Sauramo, M. Studies in the Quaternary Sediments in Southern Finland Bull. Com.Geol. du Finlande; N.O.60,p.1 -164.

MECHANICAL ANALYSIS.

Several methods may be made use of in the mechanical analysis of clays. The Beaker method, as devised by Whitney,(7) is simple. It consists of thoroughly disintegrating the clay in water and then allowing all the particles above a certain size to settle. Elutriation methods, as described by Ries,(8) have been used to considerable extent. The most satisfactory method up to date is that used by the United States Bureau of Soils.(9) Grout(10) makes use of this method but he has modified it to a certain extent. The method consists of separating the sand fractions of the clay by means of sieves and then separating the silt and clay fractions by means of a centrifuge.

Since the Lake Agassiz clays are very fine, 50-gram samples for the coarse and fine sand determinations were used, while only 5-gram samples were used for the silt and clay determinations. The samples were placed in bottles containing distilled water to which a few cubic centimeters of ammonia had been added, and were agitated in a mechanical shaker for six hours; after which the 50-gram samples were washed through sieves to obtain the coarse and fine sand fractions, and the 5-gram samples were centrifuged as described in Bulleting 84, United States Bureau of Soils, to obtain the clay and silt fractions.

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(7) United States Department of Agriculture, Bureau of Soils, Bulletin 4, Page 10, 1896.

(8) Ries, H. Clays, Occurrence, Properties, and Uses. PP 138-144

(9) United States Bureau of Soils, Bulletin 84.

(10) Grout, F.F. The Relation of Texture and Composition of Clays, Jour. Am. Ceramic Soc. Vol.7, P.124, 1924.

Altogether five separations were made and in each case the particles were checked microspopically so that very few of the diameters varied from the following:

1. Coarse sand	over 0.5	mm.
2. Fine sand	0.05 to 0.5	mm.
3. Silt	0.005 to 0.05	mm.
4. Coarse clay	0.001 to 0.005	mm.
5. Fine clay	0.00 to 0.001	mm.

Six mechanical analyses were made, the samples being taken from the same section as those used for the chemical analyses. The results obtained are given in the following table:

MECHANICAL ANALYSES OF LAKE AGASSIZ CLAYS.

Sect.	Coarse Sand.	Fine Sand.	Silt.	Coarse Clay	Fine Clay.	Total.
A	0.06%	2.31%	38.89%	20.83%	38.76%	100.85%
B	0.00	3.35	92.19	1.38	3.70	100.62
C	0.13	2.52	33.49	23.99	40.72	100.85
D	0.20	1.54	36.26	23.59	39.03	100.62
E	0.005	1.33	34.50	22.06	41.31	99.20
F	0.09	1.48	29.18	23.07	46.04	99.86

As is seen from the above analyses the Lake Agassiz clays are very fine. The coarse sand only amounts to a trace, and the maximum amount of fine sand does not exceed 3.35%. The clays, with the exception of the yellow band, which is represented by (B), have an exceptionally high percentage of coarse and fine clay. Just how much of the fine clay is colloidal is very difficult to say as up to date no method that can be relied upon has been developed for separating the colloidal material. The exceptionally fine character of the clays can be explained by the fact that at the time they were laid down Lake Agassiz was of great size, and the place where the clays were deposited was at considerable distance from the ice-front, or from any of the inlets of the Lake; consequently only the very finest material would have remained in suspension long enough to have been carried so far. The yellow section (B) which contains 92.49% silt, represents a shallowing of the lake; material as coarse as this could not have been carried very far before being deposited.

The fineness of grain of both the fine and coarse clays increases with depth, and since the hygroscopicity also increases with depth, hygroscopicity should give a relative measurement of the grain of the clay.

An average of the five silt determinaions, (B), being omitted, show approximately one third of the clay to be silt. This amount is distributed fairly evenly throughout the section, although there appeares to be a slight decrease, with depth, in the size of the grains.

SEASONAL DEPOSITION

It has only been within very recent years that Geologists have turned their attention to the seasonal banding of post-glacial clays, and to the value of the banding in estimating the duration of post-glacial time. Hitchcock (11), as early as 1841, called attention to the banding of the clays in the Valley of the Connecticut and pointed out that invariably the coarser material was at the bottom of each band, and that there was a gradual diminution in fineness upwards. until at the top there was found exceedingly fine clay. He further stated that each layer may mark an annual deposit. Baron de Geer, (12) in studying the banding of the post-glacial clays of Sweden was the first to give proof that each band represented a years' deposition; consequently by correlating the varves (13) in different parts of the country and counting the total number he was able to give a correct estimate of the duration of post-glacial time. He found that approximately 12,000 years was required for the ice to leave Southern Sweden.

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(11). Hitchcock, E. Final Report onthe Geology of Mass. 2 vols. Amherst, Northampton, 1841.

(12). Geer, Gerard de, A. Geochronology of the last 12000 years. Compte rendus long. Geol. intern. 11, 1910, 1912, p. 241 - 253.

(13). Annual layers in clay and silt.

Sayles,(14) has. confirmed Hitchcock in that the banding of the clays of the Connecticut Valley represent seasonal deposition, but he further states that the clays were laid down in a glacial lake and also suggests a similar explanation for the banding of the Squantum tillite of Boston. Sauramo and Antevs, who were students of de Geers, have added valuable contributions to our knowledge of varve structure. Sauramo(15) was able to work out the rate of retreat of the ice from Southern Finland and to give us a general idea of the climatic changes that took place during the retreat of the ice; Antevs(16) made a similar study of the varve sediments of the New England States and found that the average rate of retreat of the last ice sheet from these states was one mile in 22 years.

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(14) Sayles, R.W. Mem. Mus. Comp. Zool. Harvard, 47. 1. 1919.

(15) Sauramo, M. Bull. No.50 , Commission Géologeque de Finlande.

(16) Antevs, E. The Recession of the last ice sheet in New England, American Geographical Society Research Series, No. 11.

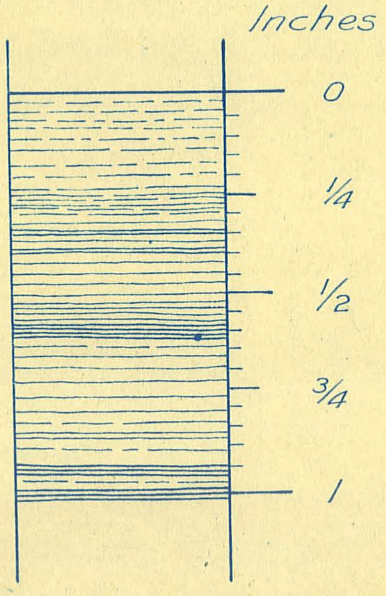

Figure 9. Drawing of section, 1 inch thick,
to illustrate planes of sedimentation
of Lake Agassiz clays.
Stanby Plant, Rupert St. Winnipeg.
9 feet 2 inches below surface level.

Reproduce on same scale.

There appears to be little doubt that the clays of the Lake Agassiz basin are varve clays, but up to date no attempt has been made to correlate them and as a result no definite time can be given for the retreat of the last ice sheet from Central North America. As the outcrops of clay are rare except in the Red River Valley, and the varves are so very thin, it appears that some other method besides that of De Geer will have to be devised for correlating the different deposits, although it is quite possible that the same varves in different deposits could be recognized by microscopic measurements.

THE DON RIVER CLAYS

As the laminae or bands of the Lake Agassiz clays were so extremely thin that it was practically impossible to study in detail the constitution of each band, it was decided to make a chemical, colloidal and mechanical study of a varve of appreciable thickness from a different deposit. The varve chosen was obrained by Dr.R.C.Wallace from the glacial clays of the Don River Valley, Toronto.

The total thickness of the varve was approximately #/4 of an inch and of this a little more than 1/2 comprised the summer part. There was no difficulty in distinguishing between the winter and summer portions of the varves. Even with the eye alone a definite break could be distinguished, and with a hand lens a well defined line between the two portions could be seen. Just why this definite break occurs between the summer and winter deposition is not known. From its position in the varve it appears to have been formed about the time that the lake was frozen over.

When dry the Don River clays are blue-ish gray and have a smooth greasy feel. They break with a concoidal fraqture and when placed in water slack rapidly.

CHEMICAL ANALYSIS

In order to determine if there was any variation in the chemical constituents of the Don River varve a chemical analysis was made of the summer and winter portions. The results obtained are given below:

TABLE 3.

CHEMICAL ANALYSES OF DON RIVER VARVE

	Summer Fraction	Winter Fraction
Silica	32.34	34.01
Alumina	12.00	15.50
Iron Oxides	4.82	5.14
Magnesia	4.31	3.64
Lime	21.20	18.25
Potash	2.20	2.83
Soda	1.80	1.75
Ignition	21.90	18.74
	99.86	99.57
Fluxes	34.33	31.61

From the analyses it is seen that the winter fraction of the varve contains more silica, alumina and iron oxides than the summer fraction. This is what one would expect, for it is quite possible that a considerable portion of the silica, alumina and iron carried into the lake during the summer, would be in the colloidal form, and this instead of being deposited with the other summer sediments would be held in suspension longer and would settle during the winter months when the lake was frozen over and as a result the water undisturbed, thus conditions being more favorable for the finer particles to settle. Potash is the only other constituent which is more prevelant in the winter fraction than in the summer. This is probably due to the greater amount of colloidal material in the winter fraction and as a result the great adsorption of potassium. Since lime and magnesia are the first products of a rock to be eroded and carried away it is natural to expect that there would be an excess of these two in the summer fraction. The amount of soda appears to be about the same in each fraction. The fluxing ingredients are slightly in excess in the summer fraction; and they make up such a high percentage of the clay that it fuses at a comparatably low temperature.

COLLOIDAL ANALYSES

The relative amounts of colloids in the summer and winter fractions of the Don River varve were determined by means of hygroscopicity measurements, the clay samples being previously heated to a temperature of 110° centigrade. The amount of water absorbed plotted against the time in hours that the clay samples were exposed to the moist atmosphere is indicated in Fig. 4. The maximum amount of water absorbed in each case is indicated in the following table 4.

Hygroscopicity Curves Of The Two Halves Of A
Don River Varve Which Have Been Dried
At A Temperature Of 110° Cent.
A = Top Half Of Varve
B = Bottom Half Of Varve

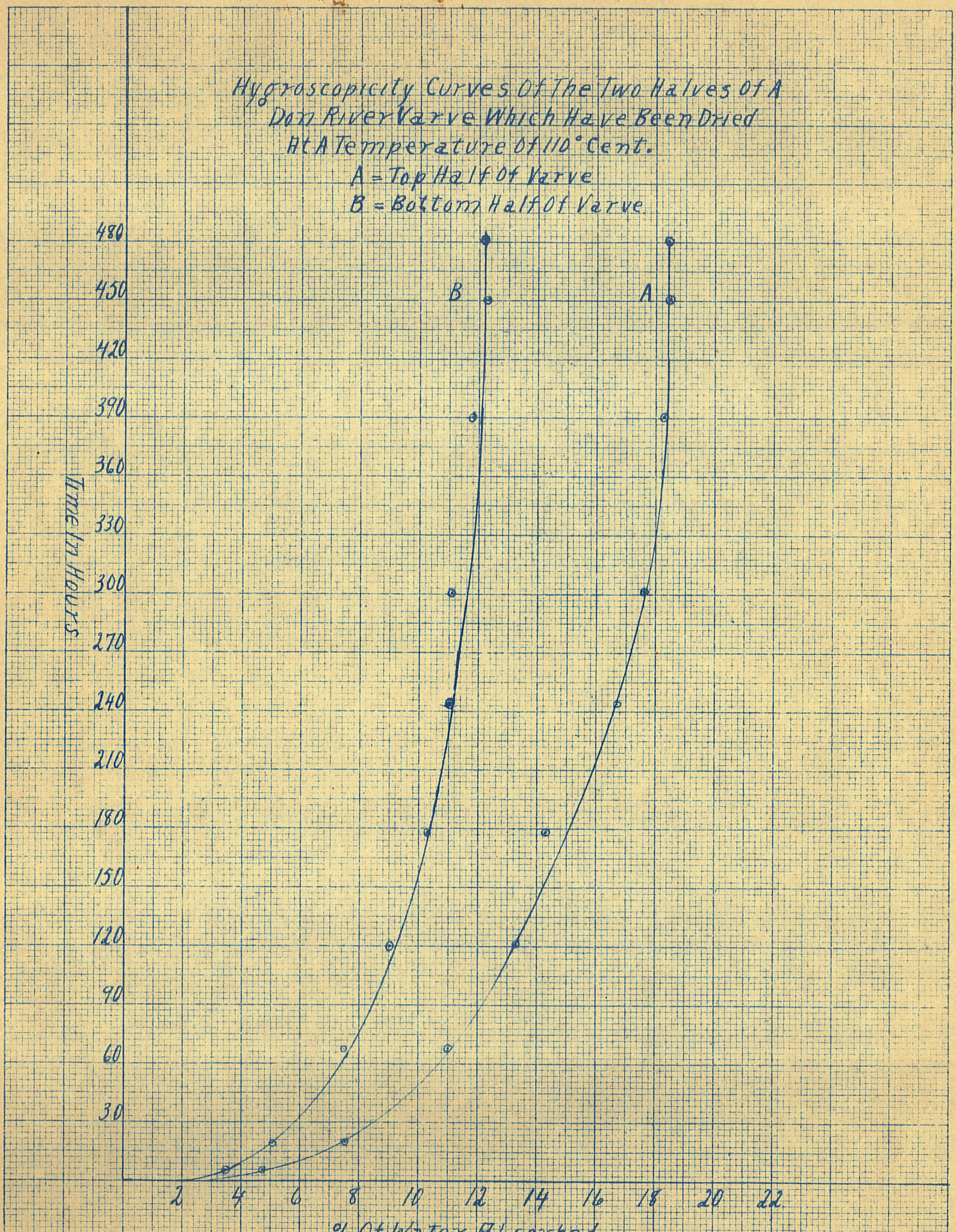

Fig. 4

TABLE 4.

HYGROSCOPICITY OF DON RIVER VARVE, DRIED AT 110° centigrade

Section	Description	Percentage of water absorbed
A	Fine Fraction of varve (Winter)	18.4
B	Coarse fraction of varve (Summer)	12.2

The results obtained in table (4) show that the colloidal content of the fine fraction of the varve, is approximately 1/3 greater than the colloidal content of the coarse fraction of the varve; and as a result if hygroscopicity is a criteria for fineness of grain, the average fineness of the Winter deposition, compared to the Summer deposition is in the ratio 3:2. This can only be proved definitely by means of a mechanical analysis of the two fractions of the varve.

MECHANICAL ANALYSIS

Five - grain samples of the fine and coarse fractions of the varve were shaken in bottles with water to which a few drops of ammonia had been added, for six hours. The disintegrated sludge was then centrifuged as described in Bulletin 84 of the United States Bureau of Soils, and finally washed through sieves. The diameters of the clay particles were checked by microscopic measurement and few grains in any fraction varied from the following:

A.	Fine Clay	0.0 to .001 mm.
B.	Coarse Clay	.001 to .005 mm.
C.	Silt	.005 to .05 mm.
D.	Fine Sand	.05 to 5 mm.
E.	Coarse Sand	over 5 mm.

TABLE 5.

MECHANICAL ANALYSIS OF DON RIVER VARVE

Section	Description	Coarse Sand	Fine Sand	Silt	Coarse Clay	Fine Clay	Total
A.	Fine Fraction of Varve (Winter)	Trace	1.30	6.44%	65.42%	26.26%	99.42%
B.	Coarse fraction of Varve (Summer)	"	6.16	47.76	33.7	11.58	99.20

The results of the Mechanical Analysis as shown above bear out in a rough way the theory that hygroscopicity is proportional to fineness of grain fre the part of the Varve which was deposited in the winter has a little more than twice as much fine clay as that part of the varve which was deposited in the summer. The ratio of the coarse clay in the winter fraction to that of the coarse clay in the summer fraction is approximately two as to one. The mechanical analysis shows very conclusively that summer and winter deposition must have taken place to form a complete varve; for in no other ways does it seem possible for grains of clay and silt to be so arranged that there is a gradual increase in size of the particles, descending from top to bottom of the varve. During the summer the temperature would be high, melting would be rapid, the streams would be swift and as a result a great deal of material would be carried into the lake. The coarsest of this material would be deposited almost immediately, very little of the finer coming down as the currents in the lake, and winds would tend to keep the water agitated to a certain extent and thus keep it in suspension. In the winter just the opposite conditions would prevail, very little material would be carried to the lake, wind action and currents would be negligible and as a result conditions would be favorable for the very finest material to be deposited. Thus for each yearly cycle a definite band of clay, grading upward from

TECHNOLOGY

A few experiments dealing with the technical side of the lake Agassiz are given in the following pages.

SHRINKAGE

Technically shrinkage is an important factor in the manufacture of clay products. There are two kinds of shrinkage - air shrinkage and fire shrinkage. Air shrinkage takes place after the clay has been moulded, and is due to the drawing together of the clay particles as the water is removed. Fire shrinkage occurs during the firing of the clay product and is due to a compacting of the mass as the particles soften under heat.

A good clay for ceramic purposes must have not only a fair average total shrinkage, about 8 or 9 per cent, but it must stand drying at a fairly rapid rate, 65° centigrade is the most common drying temperature, and when dry it must not show checks or warping.

The clay used for the shrinkage, and checking and warping experiments were taken from the Standby Plant and Kildonan Park sections, representative specimens being obtained from the yellow sandy band, the gray silty clays above it, and from the dark gray finely laminated clays below it.

In all cases the dry clays were ground to pass a 40 mesh sieve before the tempering water was added. Only the linear shrinkage was obtained and it was calculated in percentage of the original length of the wet clay. The test pieces were mouled by the wet mud process, the dimensions of the mould being 4 x 1 x 1 inches.

An attempt was made to obtain the relative shrinkage of the clay sections as indicated in Figs. 1 and 2, pages 11 and 12, of the preliminary contribution to the study of the Lake Agassiz clays, but their shrinkages with the exception of (B) which represents the yellow sandy bed, were so very similar that very unsatisfactory results were obtained.

Considerable difficulty was met with in obtaining test pieces. The clays absorbed a great deal of water in tempering, forming a very stiff pasty mass, which was very tough and sticky and difficult to work.

Test pieces were moulded using different amounts of tempering water and the effect of drying at different temperatures and the shrinkage was noted. With the exception of the yellow sandy clay all the test pieces warped and checked badly, when dried at 65 degrees centigrade , No matter what percentage of tempering water was used. The yellow sandy clay kept its shape well and with 36.4 % tempering water it gave a linear shrinkage of 12.5%. With 43.6% of tempering water the gray silty clays and the dark gray finely laminated clays, when dried at room temperature, approximately 23° centigrade, did not warp or check, but they showed far too high a shrinkage, the average being 20.2%, with 39.% tempering water the shrinkage was 17.2% and there was a slight amount of warping; 34.6% water gave a shrinkage of 12.5% and there was considerable warping, but no checking; 32% water gave a shrinkage of 11%, the product was warped badly and there was a slight amount of checking.

It appears from the above experiments that before these lake Agassiz clays can be used technically some method will have to be devised to make the clays more easily workable, to cut down the air shrinkage and to prevent the clays from checking and warping when they are drying at temperatures as high as 65° centigrade.

There are three general methods in use at the present time for correcting the above disadvantages. They are as follows (1) Coagulate the clay by means of acids, alkalies or salts. (2) Mix the clays with non-plastic material such as sand or grog (3) preheating the clays to various temperatures. Whether any of these methods will give satisfactory results with the Lake Agassiz clays has yet to be seen.

The effect of Temperature on the Colour of the clay.

In general, unburned clays owe their colour to some iron compound or carbonaceous matter, sometimes the colour is due to Manganese.

According to Ries (17), carbonaceous matter colours a clay blue, gray or black, iron oxide colours it yellow, brown or red, and iron silicate colours it green. He states further that the colour of an unburned clay may not necessarily be the same as when it is burned. A red clay usually burns red; a deep yellow clay may burn buff or red; chocolate ones usually burn red or reddish brown; white clays burn white or cream; and gray or black ones burn red, buff or white. Green clays usually turn to red on firing. Calcareous clays may burn red, yellow or gray, but usually turn cream, yellow or buff, as vitrification is approached.

Seger (18) points out that colours which a burned clay may show depends on:

1) The quantity of iron oxide contained in the clay.
2) The other constituents of the clay, e.g. alumina and lime.
3) The composition of the fire gases during the burning.
4) The degree of vitrification.

5) The temperature at which the clay is burned.

The colours of the clay sections were noted at the time the samples were heated for the temperature effects on the colloids in the clay. The clays were heated by means of an electric oven and an electric furnace. The colours obtained at the different temperatures are given in the following Table.

TABLE 6.

The colour of the Clays after Heating to Different Temperatures.

Section	Colour at 23°C.	Colour at 110°C.	Colour at 200°C.	Colour at 400°C.	Colour at 600°C.	Colour at 800°C	Colour at 1000°C.
A	Gray	Gray	Gray	Dark Gray	Brown	Red	Salmon
B	Yellow	Yellow	Dark Yellow	Brown	Reddish Brown	Salmon	do
C	Gray	Gray	Gray	Dark Gray	Brown	Red	do
D	do	do	do	do	do	do	do
E	do	do	do	do	do	do	do
F	Dark Gray	Dark Gray	Dark Gray	do	do	do	do

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(17). Ries, H. Clays, occurrences, Properties and Uses, p. 196, 1908.

(18). Seger, Seger's Collected Writings, Vol. 1 p. 109

AGEING OF THE CLAYS

In general, it is fairly well known that ageing (19) of clays often increases their plasticity. Ries (20) states that this may be due to several causes, namely, water soaking, production of colloids by hydrolysis, bacterial action or oxidation of organic matter.

The Lake Agassiz clays were studied to find the effect of ageing on the colloidal content.

A sample of each of the sections as indicated in Figs. 1 and 2 was dried at 110°C. and then the hygroscopicity of each of the sections was determined; the same samples were then spread out and exposed to the atmosphere for nine months, dried at the same temperatures as before and the hygroscopicity again determined. The hygroscopicity curves of the two determinations are given in Figures 4, 5, 6 and 7. The total per cent. of water absorbed in each case is given in the following Tables:

TABLE 7.

Hygroscopicity of Clays which have been dried at 110°C.

Section	From Surface	Percentage of Water absorbed.
A	6'9" to 7'2"	19.40
B	7'9" to 8'2"	11.70
C	9'5½" to 9'10½"	21.40
D	10'7" to 11'00"	21.00
E	13'6" to 13'11"	21.50
F	18'5" to 18'10"	24.40

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(19). Ashley H.E. The colloidal matter of clay and its measurement U.S.G.S. Bull.388, p.14.

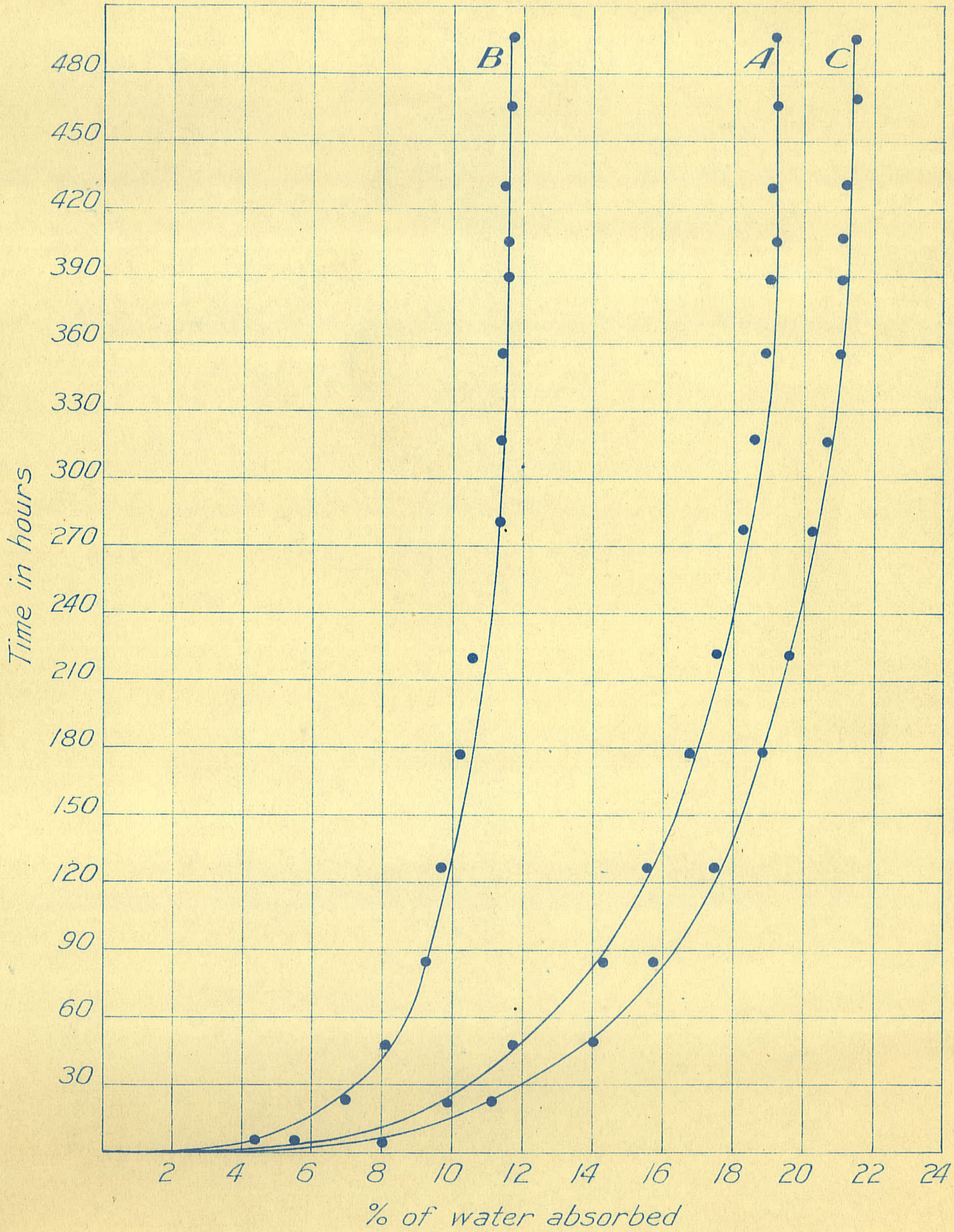


Figure 5. Hygroscopicity curves of clay samples which have been dried at a temperature of 110°c

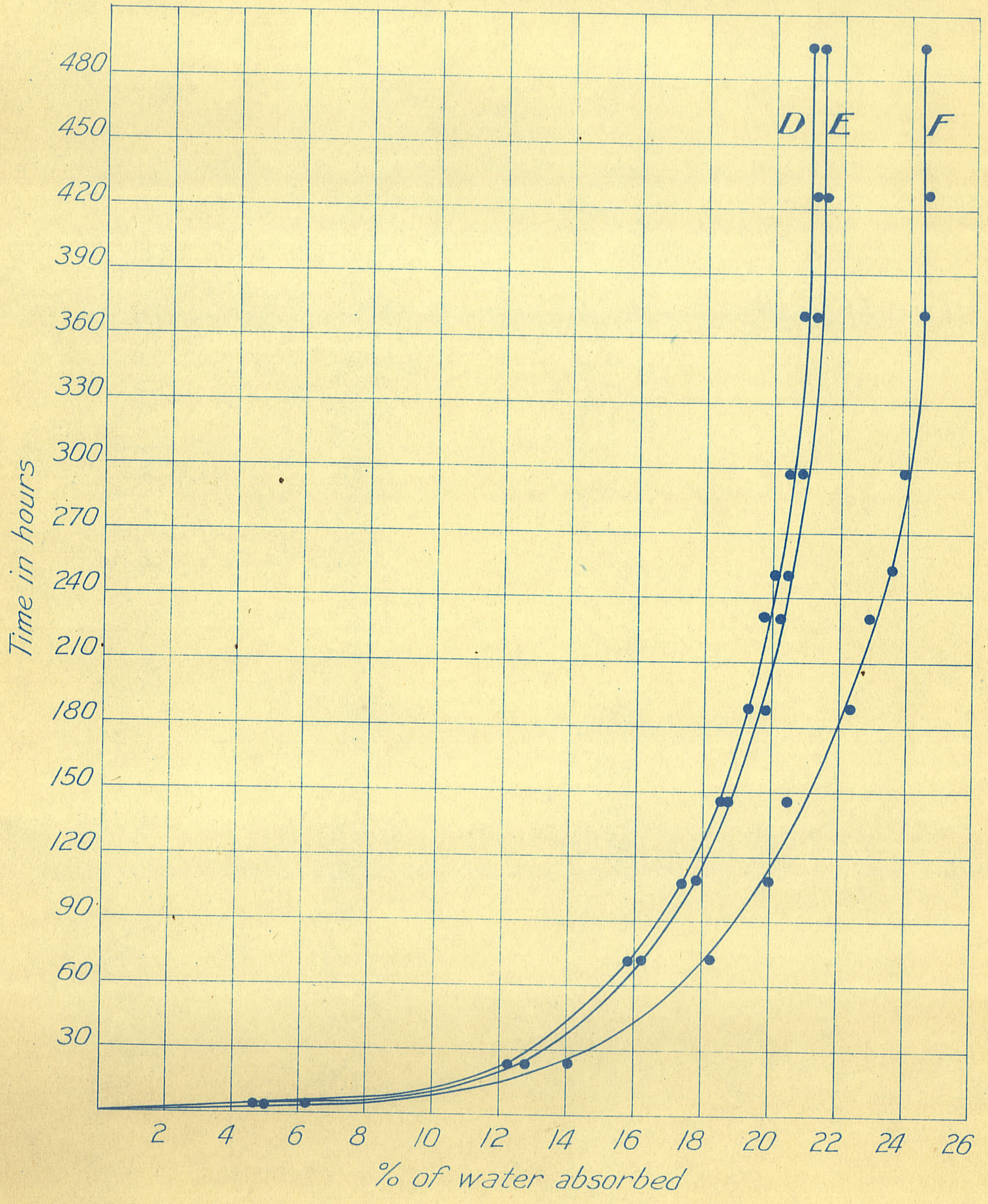
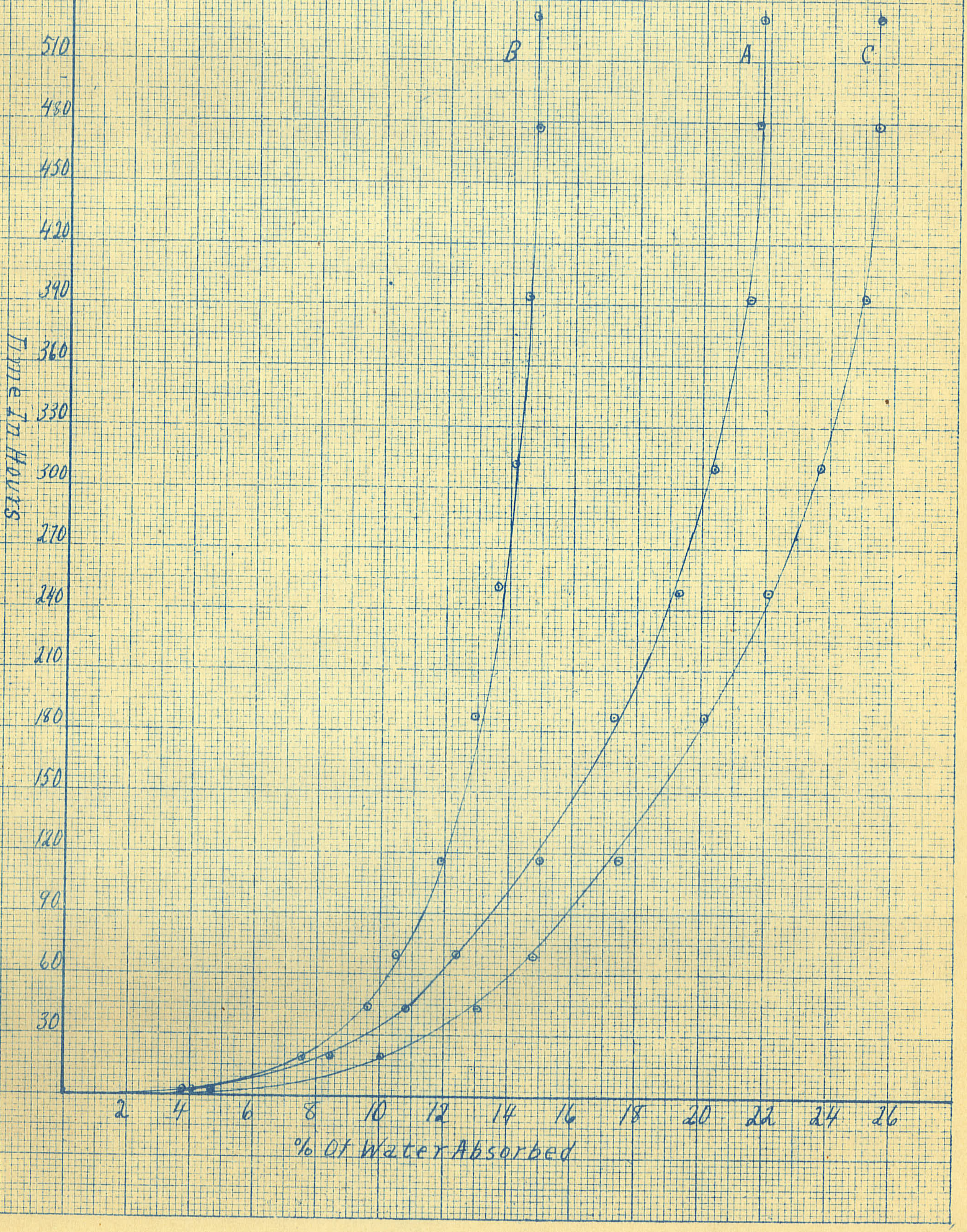


Figure 6. Hygroscopicity curves of clay samples which have been dried at a temperature

Hygroscopicity Curves Of Clay Samples, Dried At 110°C
After Aging Nine Months



Hygroscopicity Curves of Clay Samples, Dried
At 110°C After Aging Nine Months

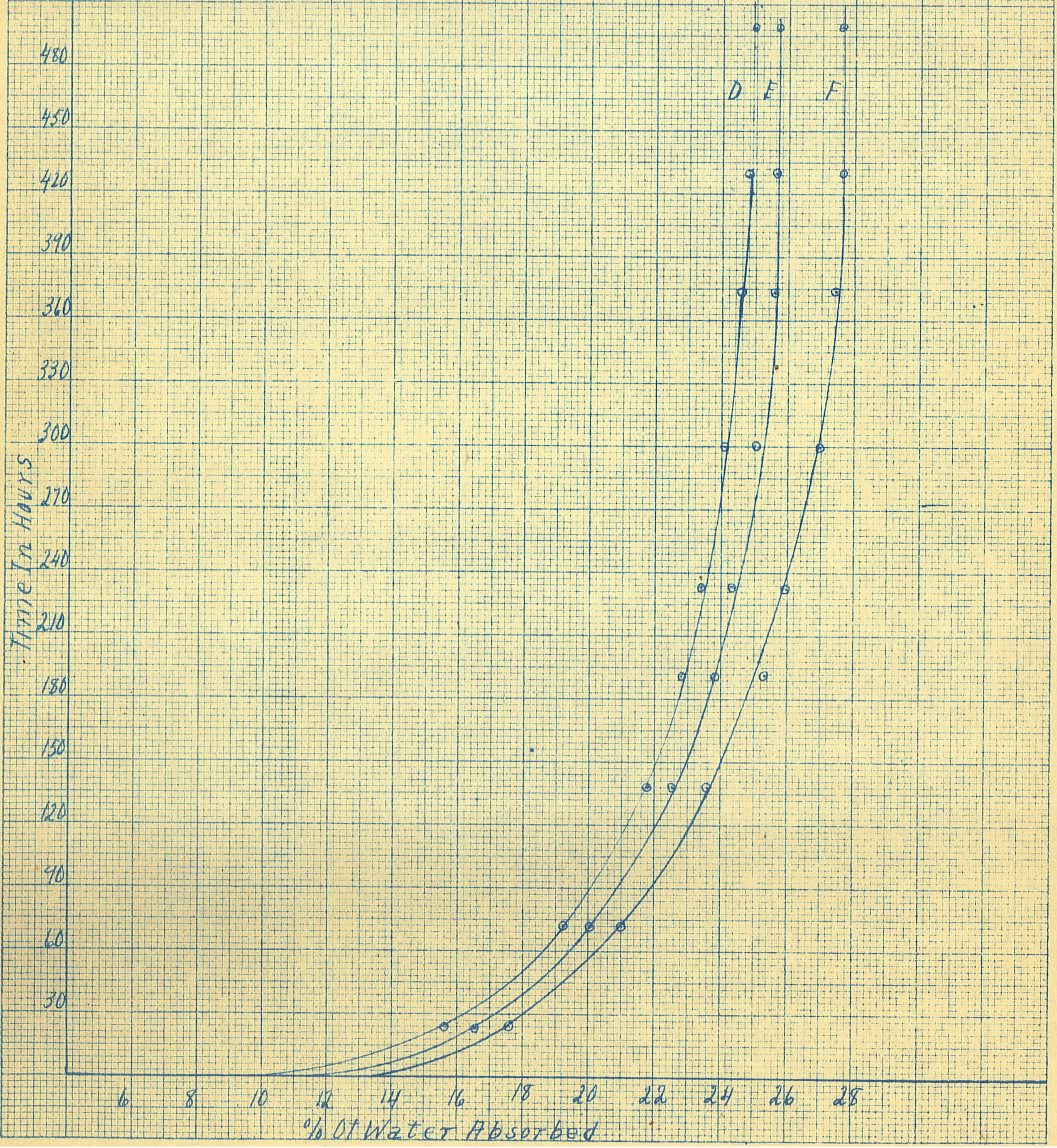


TABLE 8.

Hygroscopicity of clays which have been dried at 110°C. and then exposed to the atmosphere for 9 months.

Section	From Surface	Percentage of Water absorbed
A	6'9" to 7'2"	21.90
B	7'9" to 8'2"	14.82
C	9'5½" to 9'10½"	25.56
D	10'7" to 11'00"	24.95
E	13'6" to 13'11"	25.63
F	18'5" to 18'10"	27.61

TABLE 9.

SUMMARY OF TABLES 7 and 8

Section	From Surface	Table	Table	Increase in Percentage of water absorbed.
A	6'9" to 7'2"	21.90	19.40	2.50
B	7'9" to 8'2"	14.82	11.70	3.12
C	9'5½" to 9'10½"	25.56	21.40	4.16
D	19'7" to 11'00"	24.95	21.00	3.95
E	13'6" to 13'11"	25.63	21.50	4.13
F	18'5" to 18'10"	27.61	24.40	3.20

In the above summary it is seen that if there are subtracted the results obtained in Table 8. (Hygroscopicity of clays which have been dried at 110°C. and then exposed to the atmosphere for 9 months) and those obtained in Table 7 (Hygroscopicity of clays which have been dried at 110°C.) the results tabulated in the column headed "Increase in Percentage of Water absorbed" will be obtained.

In every case the quantity of colloidal material in the clay sections has been increased by the ageing of the samples. The increase in colloidallity does not follow any definite order and it is difficult to account for the relatively low increase of A.

SLACKING

By slacking is meant the property that clays possess of falling to pieces when placed in water. This is an important property technically, as easily slacking clays temper more readily. Some clays slack almost instantaneously, while others may take several days and may finally have to be ground.

The time of slacking of a half-inch dry cube of the different sections of the Lake Agassiz clays was noted as indicated in Table 10.

TABLE 10.

Time of slacking of the clay sections.

Section	From Surface	Time of slacking.
A	6'9" to 7'2"	12 minutes
B	7'9" to 8'2"	2 minutes
C	9'5½" to 9'10½"	13 minutes
D	10'7" to 11'00"	13.5 minutes
E	13'6" to 13'11"	14 minutes
F	18'5" to 18'10"	15 minutes

Section B . was the only one that disintegrated completely in the time indicated; the other sections having some hard shale-like material remeining.

SUMMARY

LAKE AGASSIZ CLAYS

1. Practically no leaching has taken place since the clays were deposited as indicated by the high percentage of lime and magnesia in the chemical analyses.

2. The high total percentage of fluxing ingredients in the clay limits it technically to the manufacture of common brick, sewer pipe and drain tile.

3. Temperatures from 200 degrees centigrade upwards gradually destroy the colloids in the clay, and at approximately 1000 degrees centigrade the colloids are completely destroyed. This gradual destruction may have taken place either by an aggregation of the colloid particles to form particles above the colloid size or by the colloids becoming irreversible.

4. In order to correlate the Lake Agassiz clays it will be necessary to study the available sections microscopically as the varves are of such leaf like thinness.

5. Technically the Lake Agassiz clays in their natural state are of little use. They slack rapidly , burn to a good color and their colloidality increases with ageing, but they are very difficult to work,requiring a large amount of tempering water and then forming a tough sticky mass which on drying checks and warps badly and shows far too high an air shrinkage.

DON RIVER CLAYS

1. The varves obtained from the Don River consisted of two well defined parts, separated by a distinct line. The upper portion of the varve which consisted chiefly of clay was deposited in the winter while the lower portion of the varve which consisted chiefly of silt and fine sand was

deposited in the summer.

2. Chemically the summer and winter fractions of a varve differ widely. The winter fraction contains more silica, alumina, iron and potash while the summer fraction contains more lime and magnesia. The excess of silica alumina and iron in the winter fraction is due to these constituents being partly colloidal and as a result requiring a longer time to settle, consequently being at a maximum in the winter fraction.

3. The colloidal content of the winter fraction of the varve is approximately 1/3 greater than that of the summer fraction.

4. The mechanical constitution of the varve bears out in a rough way the theory that Hygroscopicity is proportional to fineness of grain.

5. The mineral constituents of a varve are so arranged, that they could only have been deposited in one manner, namely, in fresh water and during a yearly cycle.