SUMMARY DESCRIPTION OF THE METHOD DESCRIBED FOR DETERMINING THE VOLUME OF A CLOD AND ITS AIR CONTENT.

1) Wet Clods. The clod, which can weigh up to 500 gm., is placed on a suitable wire platform, is weighed in air and then immersed in a beaker of paraffin, put in a small desiccator and evacuated for 5-10 min. using a good water pump. The desiccator is then gently bumped to remove any large bubbles around the clod, air is let in and the clod left in the paraffin overnight. It is then weighed in the paraffin, taken out and left to drain hanging in a beaker which is covered with a piece of wet cardboard. After 20 min. the thick layer of paraffin at the bottom of the clod is removed by touching it with a piece of filter paper, particular care being taken to remove the paraffin from the wire in contact with the clod. It is then weighed in air, replaced in the beaker, and after a further 10 min. draining is touched again with filter paper and reweighed. If the weight has changed by more than about 0.02-0.03 gm., the process is repeated.

2) Damp clods. The only difference from the wetter clod is that the time of evacuation on the water pump should be lengthened somewhat, probably to about 15-20 min.

3) Dry clods. The differences between this and the preceding ones are that dry paraffin must be used, at least 30 min. on the water pump should be given, and during draining the cardboard on the beaker should be saturated with paraffin and not water.

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II b 3

NOTES ON SOME CANADIAN "SILTS"

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One half of the area of the Dominion of Canada consists of one of the most interesting geological phenomena of the world, the Canadian Shield. This vast area of 1,825,000 square miles, taking its name from the shape of its outline, consists of rocks of Precambrian age. It is part of a continental mass which, in Precambrian time, extended far beyond present limits. During succeeding geological periods, these ancient rocks were covered by sedimentary deposits which still remain as the surface rocks outside the Shield but which have been almost completely eroded from the entire area of the Shield itself by repeated glacial action. The resulting topography is remarkably uniform in general, although exhibiting great irregularity in local detail. Low relief is an almost universal feature of the shield, the smooth flat-topped character of the rolling hills being similar across almost the whole continent. An unusually large proportion of the Shield is covered by water - the lakes and rivers of which have made canoe travel in the Canadian North almost legendary.

Vegetation falls into two divisions, the southern wooded belt constituting Canada's great coniferous forest resource, and the northern area which is commonly called The Barren Lands, lacking trees but covered largely by "muskeg" and similar organic deposits, usually overlying permanently frozen soil ("permafrost") or solid rock at shallow depths. As would be expected, the soils found in the Canadian Shield are all glacial or glacio-fluvial deposits, in view of the geologically recent retreat of the last ice sheet. The sands and gravels are found in typical glacial deposition formations such as moraines, eskers and drumlins. Fine grained soils are also found, some deposits extending over relatively large areas. This paper presents some notes on progress in a study of typical examples of these somewhat unusual soils.

These fine grained soils of the Canadian North are found in many different types of deposit. Some are quite extensive, the well known "Clay Belt" of northern Ontario and Quebec covering several thousand square miles. Many of the deposits can be linked directly with the known locations of glacial lakes, the outlines of some of which have been traced in great detail by Pleistocene geologists, frequently by detailed study of their old shore lines which can sometimes be followed for miles even by the untrained eye. Other deposits may be correspondingly small in extent, occurring at outlets from existing lakes and in eroded stream beds. Engineering operations are revealing still other deposits, as cuttings are made for roads and railways and excavations for building operations. The development of Canada's greatest iron mine has revealed one of the most unusual deposits in the bed of a large lake which had to be drained in order to gain access to high-grade iron ore, located beneath its surface by geophysical exploration carried out on the ice during winter.

The soils have the common appearance and feel of clays; they have been and still are described by all but such investigators as "clays", even in official geological reports. The productivity of the resulting surface soil has resulted in extensive agricultural development in some locations (such as the "Clay Belt") and the "clayey" character of the resulting agricultural land, especially after rain, is a matter of more than local comment. Certain unusual effects of engineering operations in such soils, however, have given some indication that the soils are not clays of the ordinary sort. Pile driving, for example, has been found to reduce bearing capacity; some disastrous slides have been even more potent indicators of uncommon soil conditions. And the known geological history of the deposits points in no uncertain manner to soils which are most certainly not true clays, despite all that the mechanical analysis of their particle sizes may suggest.

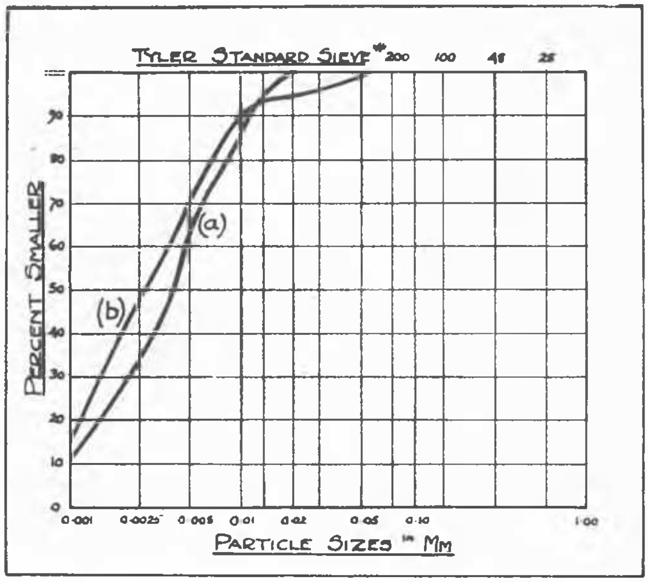
Typical of one extreme in the range of these fine-grained soils is that of which a mechanical analysis is shown in Figure Two (the Lake Superior soils). This sample is typical of the bands of fine grained soils encountered in excavations in glacial sands and gravels along the north shore of Lake Superior, general locations of all samples being indicated in Figure One. Although slightly "sticky" when wet, these soils will not give any value for either of the Atterberg consistency limits, displaying their granular character sometimes very clearly when under test. Soil with an identical grading curve, taken from the bed of Lake Superior some miles to the east, is similar in character but it does exhibit sufficient plasticity to give values of 24.1% and 17.3% for the Lower Liquid and Lower Plastic Limits respectively. All these soils exhibit no cohesion when tested for shear strength but behave as though they were granular in nature, giving angles of internal friction of about 20° when fully consolidated. The change in the plastic properties may indicate the effect of "weathering" upon the soil particles when exposed, as in the bed of Lake Superior.

Map of the Dominion of Canada showing the Canadian Shield and Locations of Soil Samples.

FIG.1

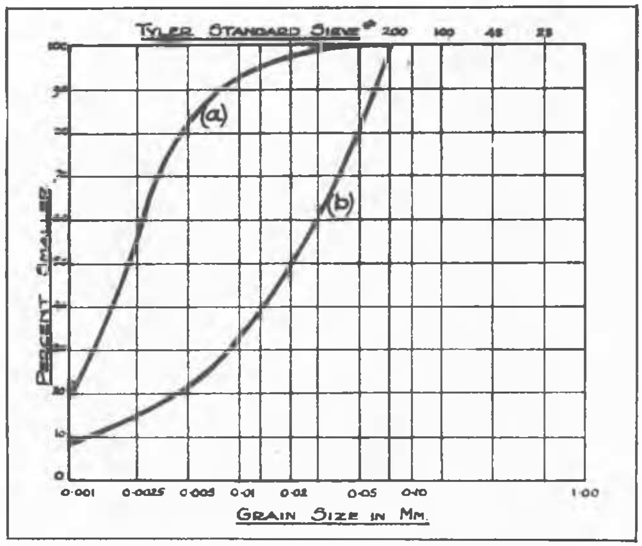
On Figure Three is shown the particle size grading curve for a fine-grained soil from the upper reaches of the Peribonka River, north of Lake St. John, near the "centre" of northern Quebec. When wet it had the appearance of liver and could be handled in thin pieces just as if it were meat It did not have a clay-like feel, but upon testing gave a P.I. of 7.6% and a Lower Liquid Limit of 30.8% - possibly due to the extreme fineness of the constituent particles.

By way of contrast there is given in Figure Three the particle size distribution curve for a much more clay-like soil from the Lake St. John region, Quebec. The striking change in the curvature of the analysis curve will at once be evident. Despite the much greater proportion of coarser particles in the Quebec soil, it is very much more "sticky" to the touch than the soil represented by the samples already described. Its true character, however, is shown when it is disturbed, as in the process of excavation. On one large construction job, soil of this type started to flow from the toe of the pile upon which it was being dumped



Particle Grading for (a) Lake Superior Soils; and (b) Malartic Soils.

FIG.2



Particle Grading Curve for (a) Soil from Peribonka River; (b) Lake St. John Soil.

FIG.3

from large railroad cars. Following the sloping configuration of the ground, it eventually formed a "river of mud" the end of which would advance thirty seconds after another carload of soil had been dumped at its source, 1,200 feet away.

Study is being made of the significance of the reversal of concavity of the grading curve for such soils as those described. It is possible that this Lake St. John soil was deposited from sea-water rather than from glacial outwash or in a glacial lake, but the recent geological history of the location from which it comes is unusually complicated and is not yet known with any certainty (Legget, 1945). The fluidity of the soil when once disturbed is a feature common to many of the fine-grained soils of the Shield, irrespective of the shape of their grading curves; it is referred to later in more detail.

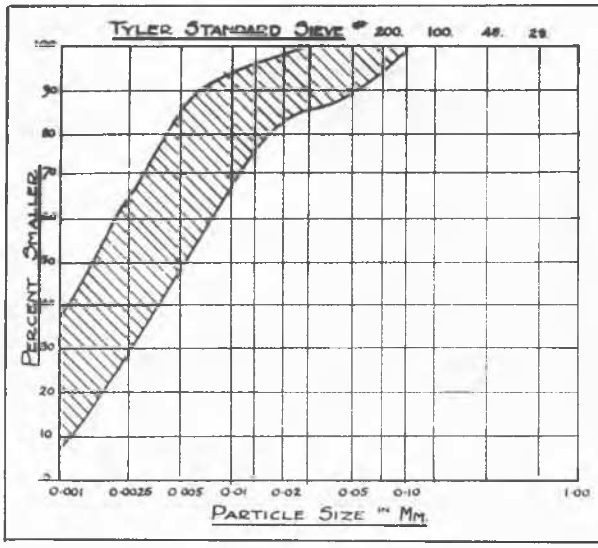
The next soil to be mentioned is typical of the deposits of the "Clay Belt", coming from the Malartic district of northwestern Quebec. Its grading curve is shown in Figure Two. This area is known to have been the bed of glacial Lake Barlow-Ojibway. Soil deposits usually are about forty feet thick over bedrock, fifteen feet of sand being overlain by twenty-five feet of "clay". In place, this soil is hard and compact, exhibiting some varving but not to any marked degree. When disturbed, as by being walked upon, it appears to be a typical sticky clay. Atterberg tests give, as common values for Lower Plastic and Lower Liquid Limits, 13% and 35%. When undisturbed samples of the soil are subjected to shear tests, they fail to reveal any true cohesion, displaying angles of internal friction of 23° under full consolidation. Possibly the most remarkable feature of the soil, however, is revealed by moisture content tests of samples just as they are removed from sampling tools. Natural moisture contents are regularly found to be slightly above the corresponding Lower Liquid Limit. Contrasting so markedly with their compact natural appearance, in place, this characteristic of the soils makes their fluidity when disturbed understandable. It suggests also some possible features of their deposition. It is a phenomenon which is shown so much more vividly by the soil yet to be mentioned that this may first be described before some tentative conclusions are suggested.

SOIL OF STEEP ROCK LAKE;

Steep Rock Lake was a narrow N-shaped rock-bound body of water, about ten square miles in area and typical of the most beautiful lakes of the Canadian Shield, located 140 miles west of Fort William, Ontario. The Seine River flowed through the Lake on its way to Lake of the Woods, forming a part of one of the old water transport routes to the West of Canada. After valuable iron ore had been located beneath the waters of the Lake, it was decided to dam its two ends, to divert the Seine River to another course, and then to pump the Lake dry in order to gain access to the ore. This great engineering undertaking was successfully carried out; fourteen centrifugal pumps started pumping into their twenty inch diameter discharge lines in December 1943. Water level fell by about six inches per day so that in the summer of 1944 a good deal of the bed of the Lake was exposed. Pumping continued and excavation of overburden began. Ore production started in May 1945, 505, 375 tons of ore being shipped that season; 830, 409 tons were moved in 1946, and just over 1,200,000 tons in 1947. The bottom of the open pit is now over 300 feet below the original water level of the Lake, pit operations providing a most striking spectacle. The development of the Mine constitutes an epic of Canadian engineering (Samuel, 1945)

As first revealed, the sediments in the bed of the Lake were very wet and "slimy", covered in some places with up to two feet of black muck having apparently an appreciable organic content. Since the exposed surfaces froze as the water level was lowered during the winter of 1943-44, and in view of the drastic change in groundwater conditions, serious slides developed in the spring of 1944. These were to be expected and were readily explained, being vivid evidence of the normal process of geological adjustment, speeded up considerably by man's interference with local natural conditions. Study of the slides led to some detailed studies of the soil conditions in the lake-bed. These had the utilitarian object of assisting with the development of stable soil conditions around the open pit but they are also beginning to yield scientific data of unusual interest. Stability around the pit has been achieved by judicious trimming of slopes, control of the movement of any soil which was expected to move, and the start of vegetation on finished slopes.

Many mechanical analyses of particle sizes in individual soil samples have been made, using surface samples and also those from deep borings. These borings have disclosed depths of soil up to 150 feet above the bed-rock, with sand and gravel deposits in some places immediately overlying the rock surface. Figure Four shows the envelope within which fit all the grading curves so far determined. The uniformity of the soil is really most striking, despite some differences in appearance between samples, most of the grading curves being close to the mean suggested by the envelope. It will be seen that the percentage of "clay-size particles" (using any one of the accepted classification schemes) is high. The soil in place has every appearance of clay, being generally of a dull grey colour, smooth to the touch, and unusually sticky when wet and disturbed. Its behaviour, however, belies its appearance.

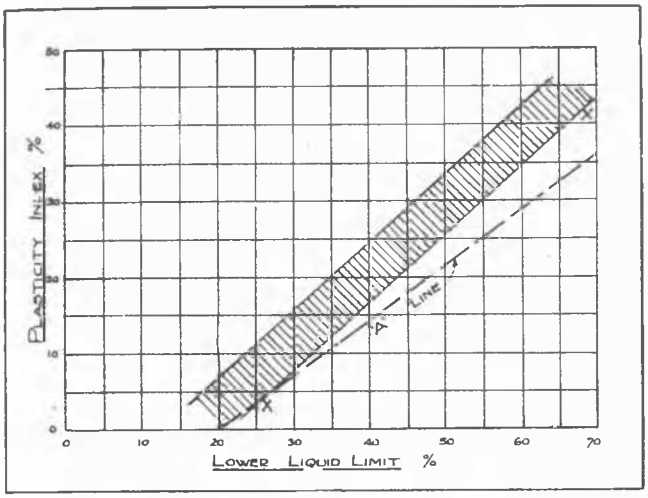


Envelope of Particle Grading Curves for Soils from Steep Rock Lake.

FIG.4

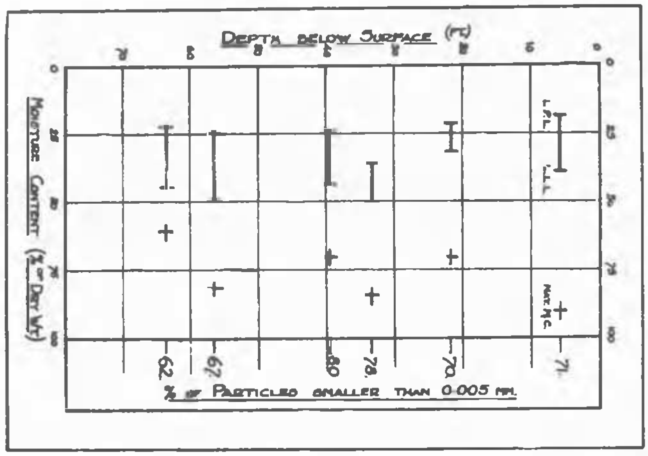
Atterberg consistency limits have been determined for well over one hundred samples. The results are summarised in Figure Five, from which it will be seen that they give a consistent relationship between Liquid Limit and Plasticity Index. The values indicated conform to Professor Arthur Casagrande's classification of inorganic clays of low compressibility, as is indicated by the Casagrande 'A' line which is also included in the diagram. The corresponding inter-relation for the Malartic soils is also shown; the agreement is quite remarkable. Many samples of the Steep Rock soil have been tested for shear strength; all fail to exhibit any true cohesion, giving fairly constant values for the angle of internal friction of about 20°, when fully consolidated.

Natural moisture contents were taken of all undisturbed samples, from the start of soil studies. These showed an almost invariable excess of water in the samples above that required for standard Lower Liquid Limit tests.



Envelope of "Liquid Limit - P.I. Ratios" for over one hundred soil samples from Steep Rock Lake; Line "X - X" gives values for Malartic Soils.

FIG.5



Moisture content data for samples from typical deep boring at Steep Rock Lake.

FIG.6

This unusual feature of the test results made them suspect. Many check tests were therefore made but preliminary findings were confirmed. Figure Six, which shows the log of one of the deep borings, presents typical results. (It may be noted that the moisture contents shown were all checked on pairs of identical samples in two different laboratories, with complete agreement, within normal limits of experimental error). It will be seen that the difference between natural moisture contents and Lower Liquid Limits averages about 33% and is reasonably constant throughout the depth of the hole. It will be noted also that there is no significant change in soil character with increasing depth, a feature sometimes found with deep deposits of fine grained soils.

The unstable character of the soil will be at once apparent. This instability explains some of the slides which have occurred as "mud runs", following the disturbance of soil at the bottom of steep slopes. Such mud runs occur with surprising speed, when once started, some involving as much as 300,000 cubic yards of material. After movement has stopped, the exposed soil appears to be more stable than previously and no subsequent movements have been detected in soil which has once "flowed". The surface of such slides dries out more quickly than the normally exposed soil. All these observations fit with the concept of a sudden loss of excess water from the soil, when once it is disturbed. More definite confirmation was given when excavation had to be carried out in the exposed lake-bed. This was done by means of a large dragline excavator. Digging was stiff and very sticky. Once the soil was dumped from the bucket, however, it was transformed into a liquid state and flowed away in a well defined stream. This is shown in the accompanying photograph, Figure Seven.

Despite this marked instability of the soil in the lake-bed, it behaves quite normally when not disturbed. As has been indicated, stable slopes now exist around the open pit and no movements have been observed in them for more than a year. Within a month or two of the exposure of the lake bottom, adjacent to the site of the open pit, a road had been constructed over the still wet and sticky surface, founded on a fill of well graded sand and gravel

"Mud - Run" of Steep Rock Soil after disturbance by excavation.

FIG.7

(obtained from an adjacent glacial deposit) about four feet deep. The fill was designed to give safe bearing pressures upon the silt when carrying loaded ore-trucks; the road has performed quite satisfactorily with no deformation of the fill or underlying soil, and only routine maintenance of the surface, despite heavy all-year round traffic of loaded 23 cubic yard diesel-operated trucks.

Remolding of soil samples was naturally tried very early in the programme of soil testing and showed clearly the complete change of soil structure caused by such manipulation. Repeated trials have been made to obtain small cylinders for unconfined compression testing but without success. The soil, in its natural state, has a blocky structure which, while not interfering with the cutting of large samples for shear tests, makes the preparation of small prisms impossible. The structure bears a striking similarity to a soil structure developed by Dr. Leo Casagrande in some of his experiments on the electrical treatment of clay soils (L. Casagrande, 1947) This coincidence is naturally to be followed up in the hope that it may lead to significant findings. It serves to confirm the impression, induced by detailed consideration of the test results so far summarised, that the mode of deposition of the soils in Steep Rock Lake is responsible for their unusual structure and high moisture contents.

Throughout all exposures of the soil so far examined, varying of the soil is very clearly demonstrated. So remarkable is this varving that Dr. Ernst Antevs, renowned expert on varves, spent some weeks at the Mine in 1946 and made a complete study of the varves, detecting five distinct series; his report will be published in 1948. The authors have followed up the work of Dr. Antevs by starting a detailed study of the soil types in individual varves. This work has only just been started but the results are already interesting (Bartley and Legget, 1947). Little difference is found between the grading curves for the particles in the light and dark varves, some difference is noted in the respective Atterberg Limits, and appreciable differences in the relative moisture contents of the several varves. Apparently the principal difference is one of soil structure and not soil composition. It is somewhat difficult to reconcile this with the generally accepted theory of alternating winter and summer deposits.

Photographs of particles from some of the soils described, taken with the aid of an electron microscope (through the courtesy of Dr. E.F. Burton and members of the staff of the Department of Physics, University of Toronto) fail to disclose any of the typical elongated particle shapes of the true clay minerals. This was to be expected since all the evidence presented suggests that the soils described consist of "rock flour" i.e. granular particles of relatively fresh rock minerals, despite their small size. Deposition of these soils, with so high a colloid content, must have been related to the varying electrolytic property of the water in which they were suspended,and this might have given rise to the thixotropic condition exhibited by the Steep Rock soils. Much work has yet to be done before a full understanding of the true character of these soils of northern Canada is reached, but it is hoped that this note of progress will be of interest to the International Conference if only for comparison with similar soils found in other countries.

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II b 4

ANALYSIS OF THE LATEST AMERICAN TESTS ON SOIL CAPILLARITY

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INTRODUCTION.

In the past five years various laboratory tests on soil capillarity have been made in the United States using both vertical open tubes of various diameters filled with dry or practically dry soil powder and capillarimeters. A comparative analysis of the results of these investigations is made in this paper.For comparison purposes some capillary tests in glass tubes and in fibrous materials are also referred to.

1. CLASSIFICATION OF TESTS.

The tests analyzed in this paper have been made:

(A) by the physicists of the Bell Telephone Laboratories 1);
(B) by the physicists of the Louisiana State University 2);
(C) at Princeton University 3), using both vertical open tubes with soil and capillarimeters;
(D) in the Connecticut State Hignway Department 4), using vertical open tubes;
(E) by the U.S. Army Engineers .5), using both vertical open tubes and capillarimeters;
(F) at Yale University 6) using vertical open tubes.

Hereafter the tests mentioned above are identified as tests (A), (B), (C).......

2. TESTS (A) AND (B).

(A) Strips of filter paper about 1 cm wide and about 20 cm long were suspended vertically with their lower ends dipping into a liquid. All measures to prevent evaporation were taken. The wetted portion was clearly demarcated from the unwetted by an even horizontal line. The demarcation line for this and other cases of capillary rise, is termed "wetted line," hereafter. Plotting the heights, h, of the wetted line above the water table against corresponding time t, "time-curves" were obtained. A graphical differentiation of a time-curve furnished Equation (1) corroborated by theoretic-