

LABORATORY STUDIES OF FROST ACTION IN SOILS WITH
SPECIAL REFERENCE TO THE CLAY MINERAL FRACTION

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The laboratory cold-room and its equipment have been designed to enable studies to be made under controlled conditions of all frost phenomena occurring in soils which are reasonably adaptable to investigation by laboratory methods.¹ Although this particular overall laboratory program incorporated ~~many~~ various testing methods, experiments, and analyses, it was designed chiefly to determine the quantitative effects of individual variables which influence ice segregation in soils. The variables that will be discussed in this paper are as follows: (1) gradation and percent finer than 0.02mm; (2) effect of compaction; (3) percent stone; (4) penetration of 32°F. temperature; (5) temperatures between frozen and unfrozen soil; (6) saturated clay in a closed system.²

The cold room is a walk-in refrigerator, approximately 9 ft. wide, 20 ft. long, and 6.5 ft. high. It is constructed of 22 separate panels bolted together, enabling dismantling ease and providing flexibility for expansion when and if the occasion necessitates it. The panels are faced on both sides with 20-gauge galvanized sheet metal and the room is completely insulated with 6 in. of mineral wool (vermiculite).³ A 1½ H.P. water-cooled compressor is positioned outside the cold room laboratory which supplies the Freon gas refrigerant to two unit coolers mounted at the rear of the cold room. Room temperature is controlled with a Minneapolis-Honeywell bimetallic mercury-bulb thermostat, with limits of plus or minus 2°F. The cold room has been designed to function between plus 10°F. and plus 40°F.

Located within this cold room enclosure are nine individual test cabinets insulated on the top and side with 6 in. of sheet cork. $\frac{1}{4}$ H.P. aircooled units supply the refrigerant to each individual test cabinet maintaining temperatures ranging from cold-room temperatures to -20°F . Temperature in each cabinet is controlled by a De Khotinsky bimetallic helical thermoregulator with an accuracy of plus or minus $\frac{1}{2}^{\circ}\text{F}$. Figure 1 illustrates a section through one of the cabinets.

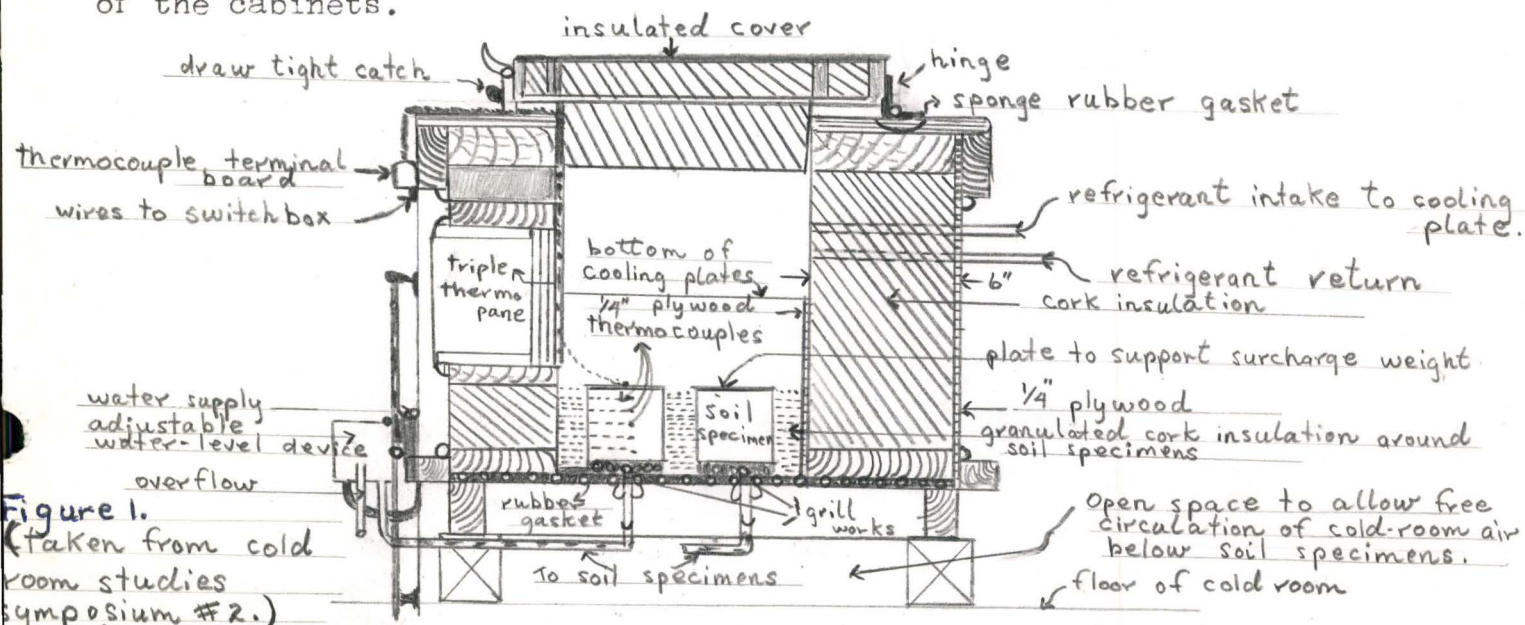
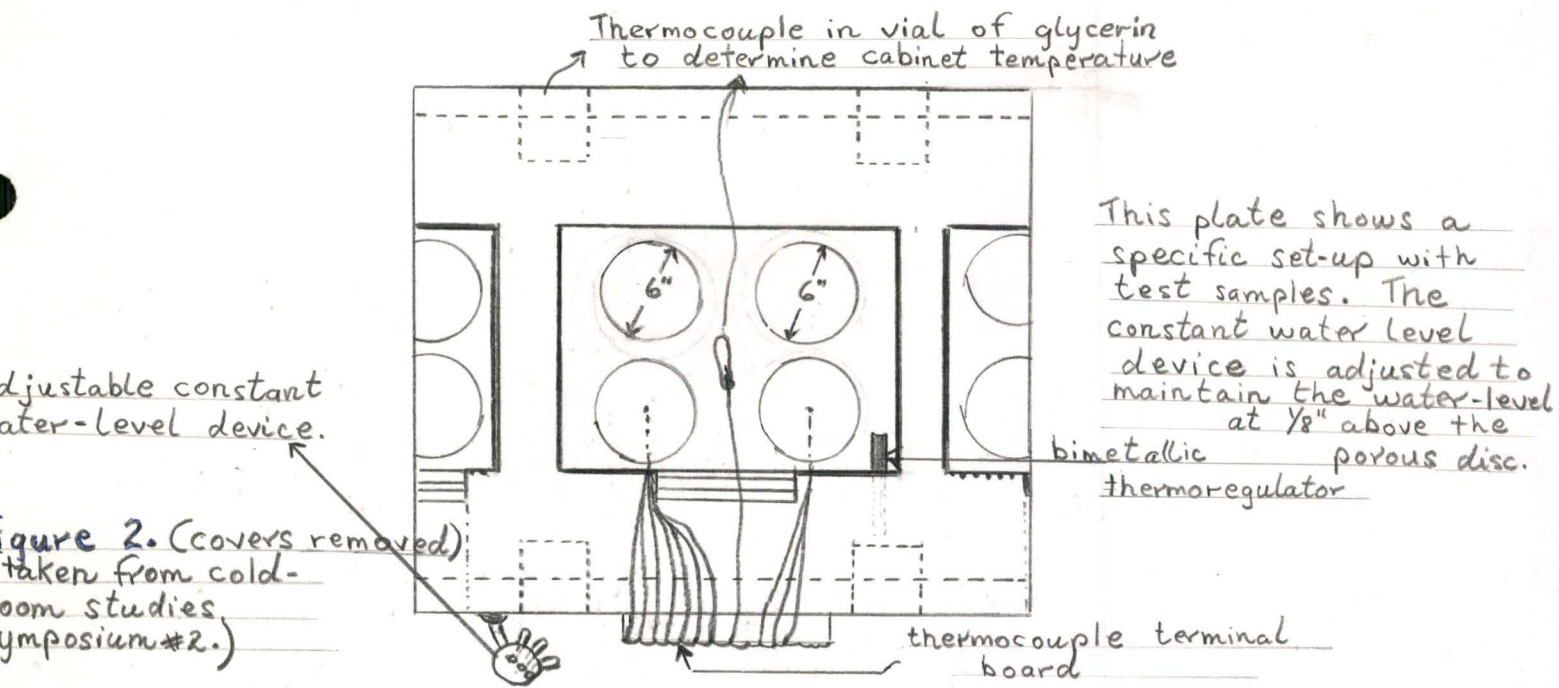


Figure 1.
(taken from cold room studies symposium #2.)

An interesting feature of the test cabinets are the bottoms which consist of open grill work to allow the cold room temperature to be applied to the bottom of the soil specimens being tested, while the tops of the samples are being subjected to the cabinet temperatures. During the freezing test process, cabinet temperatures are lowered gradually in small daily decrements in order to produce a rate of frost penetration into the soil samples simulating natural field conditions as near as possible. Samples are placed over porous discs in individual receptacles in which water can be supplied if and when necessary. These receptacles rest on a galvanized sheet-metal plate placed over the grill work. The space between samples

is insulated with granulated cork as shown in figure 1. The cabinets have an inside dimension of 19 by 19 inches and can accommodate soil specimens up to 12 in. high. Usually four samples are tested simultaneously in one cabinet. Constant-water-level devices which are adjustable over the range of the samples provide de-aired water to any specimen and they also maintain a definite water level within the specimens themselves. The temperatures in soil samples are measured by means of copper-constantan thermocouples. The thermal electromotive force produced by the thermocouples is measured by an electrical instrument consisting of a standard cell, sensitive galvanometer, and a Leeds K-2 potentiometer. Temperatures are read and recorded to 0.1°F . A toggle switchboard allows any one of 100 available thermocouples to be placed rapidly in the measuring circuit. Each testing jacket is equipped with a glass thermometer which can be read from the outside through the thermopane window. A close check of each cabinet temperature is maintained by the use of a thermocouple inserted in a glycerin-filled, rubber-stoppered glass vial, 1 inch in diameter and 3 inches long, suspended near the top of the specimens. The glycerin tends to nullify the temperature fluctuations occurring in the test cabinet during a normal operating cycle of the compressor, thus enabling an average temperature to be read and recorded.⁴ The daily average cabinet temperature is computed from the average of several readings with the thermocouple in the vial. Figure 2. attempts to demonstrate the procedure mentioned above.

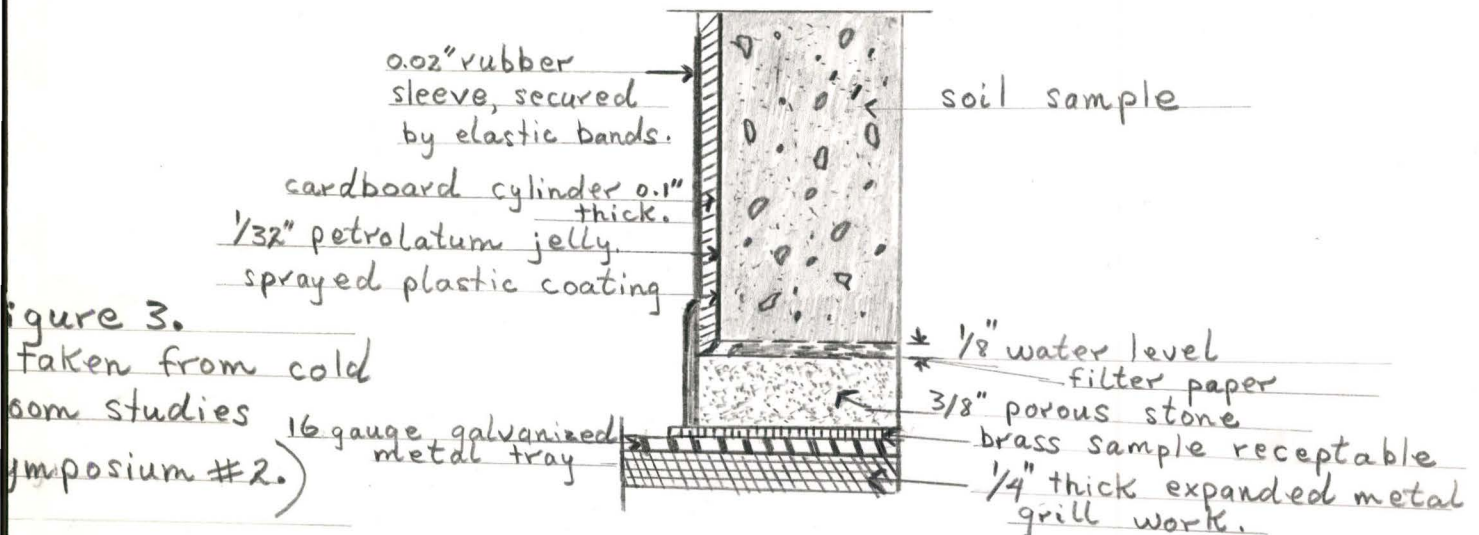


The specimens being tested in the cold room for this investigation are prepared in steel cylindrical molds to a 6 inch height. The fine-grained soils, or those soils containing grains smaller than $\frac{1}{4}$ inch, are prepared in a 4.28 inch diameter mold, and soils with stones up to 2 inches in diameter are prepared in a 5.91" diameter steel mold. The specimens are compacted to densities approximately 95% of a Modified Standard Specification (AASHO) and the base and subgrade soils obtained from beneath airfield and highway pavements are compacted to estimate natural field densities.

After removing specimens from the steel molding cylinders, the sides of the soil cylindrical samples are sprayed with a light coating of plastic material to hold the sample together during handling and to prevent water evaporation. A heavy layer of petrolatum is applied over the plastic coating and following this procedure the soil specimens are fitted tightly into 6 inch cardboard cylinders, which are open at both ends.

All soil specimens have been saturated prior to freezing. The saturation process is carried out in the cold room laboratory. Filter papers, porous discs $\frac{3}{8}$ inches thick, and brass caps are fitted to both ends of the soil specimen in its cardboard jacket, using rubber sleeves and

bands to seal against air leakage. Samples are then evacuated and saturated with de-aired water. Figure 3 demonstrates the appearance of such a soil specimen while going through the saturation process.



After saturation, the specimens are placed in one of the test cabinets with the upper cap being removed and the bottom receptacle kept in position. The de-aired water supply is connected to the bottom of each receptacle, the constant-water-level apparatus having been previously adjusted to a height such that the water in the receptacle will rise to approximately 1/8 inch above the porous stone and be in contact with the soil. The samples are insulated from each other with granulated cork, as shown in Figure 1.

Most specimens are tested under a surcharge load of 0.5 lb. per square inch (P.S.I.) in order to simulate field conditions consisting of a 6 inch thickness of pavement and base. A thin layer of bentonite clay is spread over the top of the soil specimen before the base-plate is set in order to provide a uniform contact between the steel surcharge-weight baseplate and the soil particles. The base plate is raised 1 1/2 inches by a set of four lugs so as to allow air circulation

over the top of the sample.

The thermocouples are placed at 1 inch intervals along the longitudinal axis, including top and bottom in one of the four samples in a test cabinet, providing a way of checking the temperatures within the specimen and observing the progress of freezing temperatures into the specimen. Two thermocouples are also placed at the top and bottom in one additional sample in each cabinet. The thermocouples are inserted through the side of the specimen in holes punched with a slender sharply pointed implement and finally the insertion points are sealed off with a heavy grade of grease. Testing frost action in the soil samples begins when the specimens in the cabinet have cooled uniformly to the cold room temperature of approximately 38°F. The actual freezing test is started by closing the lid and lowering the temperature in the cabinet to approximately 30°F for a duration of two days and then dropping it to 29°F for two more days and finally to 28°F for two days. After this period of six days, the temperatures within the cabinet are changed only by an amount required to maintain the rate of penetration of the 32°F. temperature in the samples at approximately $\frac{1}{4}$ inch per day. Temperatures within the soil specimens are read daily and temperatures in the cabinets are adjusted accordingly, depending upon the progress of the 32°F temperature within the sample. Readings of the vial-glycerin temperatures are obtained at intervals of 10 to 15 minutes for a continuous period of 1 to 2 hours each day in order to determine the average daily cabinet temperature. Frost-heave readings are made daily and are read to the nearest half-millimeter. Measurements are obtained with a meter stick placed on a marked point on the surcharge weights over

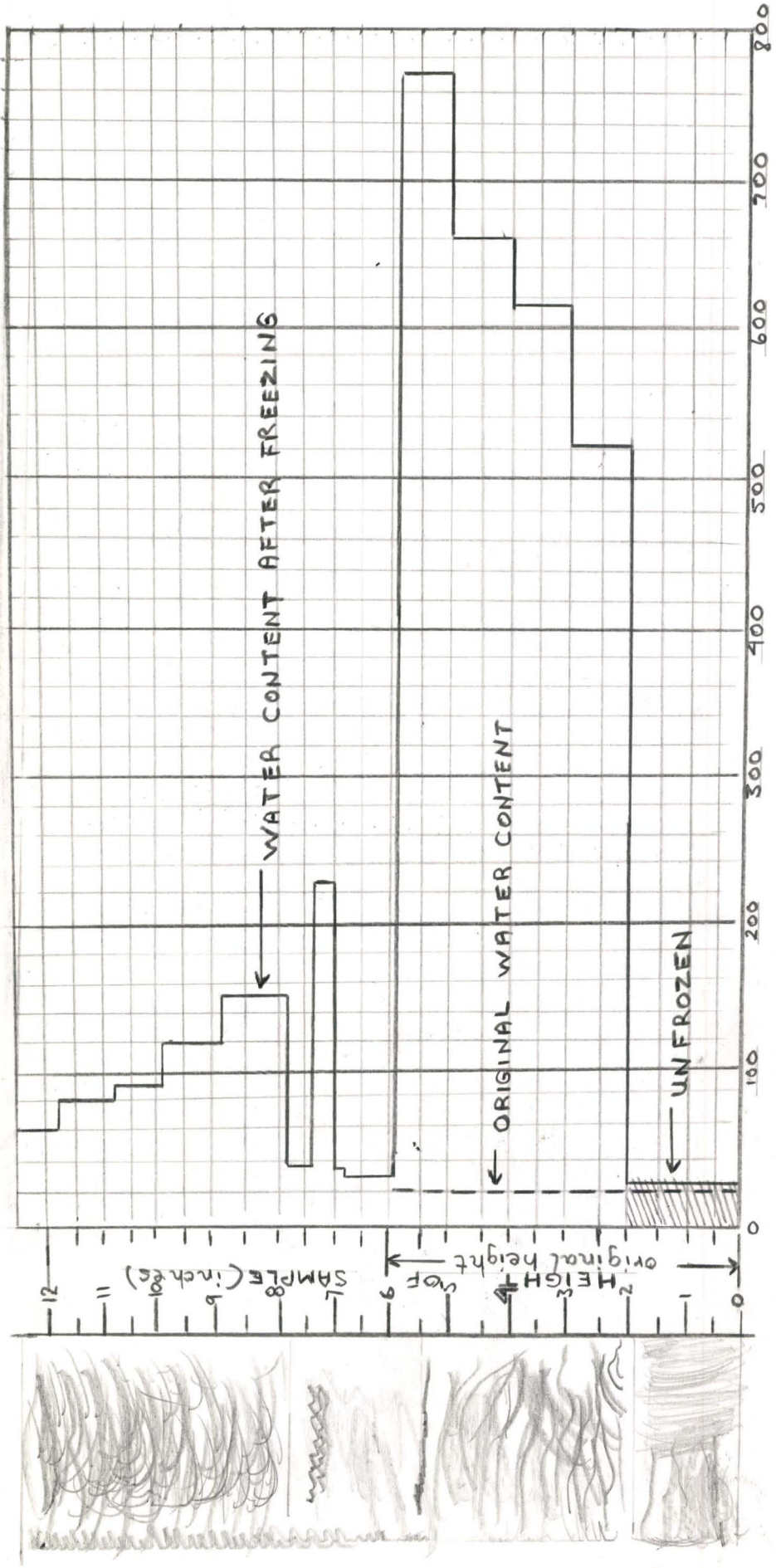
the sample; the actual reading is taken at the intersection of the stick and a steel bar across the top of the cabinet opening.

After 24 days, when testing has been completed, the soil samples are removed from their containers, weighed to determine the change in water content, and then parted vertically in a compression machine.⁵ Measurements for the amount of frost heave, and observations for the location, distribution, and magnitude of ice-lens formation are made on one-half of the specimen. The remaining half of the soil specimen is photographed and retained for supplemental laboratory tests. Water contents are obtained for every inch of the depth of the split soil sample. Figure 4 attempts to illustrate the amount of water content versus depth of a frozen soil sample, in this particular case, a soil specimen of New Hampshire Silt.

The soil samples selected for sampling in this particular laboratory program were nine basic soils ranging from a well-graded sandy gravel to a medium plastic clay. These basic soil samples were chosen for testing both in their natural gradation and in various blends with one another in order to vary the physical characteristics which influence ice segregation. Base and subgrade soils were also obtained from eleven different airfields in the northern United States, for the purpose of testing the degree of frost susceptibility.

(1) Tests On Soil Finer Than 0.02 mm.

These tests were performed in order to check the validity of past pertinent criteria concerning frost susceptible soils and to determine, for soils of various gradations, ranging from well-graded gravelly sand to uniform fine sand, the minimum



Water Content - Per Cent Dry Weight

Figure 4. Water Content Versus Depth of Frozen Sample of New Hampshire Silt.
 (.taken from laboratory cold-room studies - Symposium #2.)

percentages of grains finer than 0.02 mm. at which ice segregation will occur. Laboratory tests indicated that considerable variation in heave may result among soils having a given percent finer than 0.02 mm. Perhaps some examples can be cited here in order to illustrate these variations. Specimens of sandy gravel were blended with glacial till and the amount of soil finer than 0.02 mm. was 3 percent by weight. The result was a considerable heave of 10.9 percent, whereas some other soil samples having the same percent finer than 0.02 mm. heaved only between 1 and 2 percent. It should be pointed out that even greater differences occurred if degrees of compaction were varied. A number of experiments clearly indicated that much greater heave resulted in specimens of uniform fine sand blended with a glacial till than in the same sand blended with a silt soil.⁶ Results of other controlled experiments notably by Casagrande in 1929, Taber in 1952, ~~Bayer~~ in 1956, and by Grim in 1950 and in 1965, have illustrated very convincingly the movement of various types of pavement slabs 3 ft. square resting on different kinds of soil contained in specially constructed boxes in which the water supply was regulated. These researchers found that the maximum heave of slabs laid on silt varied from 2.3 to 3.8 inches, whereas the heave of similar slabs laid on fine sand was but from 0.02 to 0.13 inches.⁷ Thus, according to their results, it appears that under natural freezing conditions and with sufficient water supply one should expect considerable ice segregation in nonuniform soils containing more than 3 percent of grains smaller than 0.02 mm. and in very uniform soils containing more than 10 percent smaller than 0.02 mm.

No ice segregation was observed in soils containing less than 1 percent of grains smaller than 0.02 mm., even if the ground-water level was as high as the frost line.

When making a careful analysis of the results from many different laboratory-controlled studies, it appears that the great difference in heave, at approximately equal percentages by weight of soil grains finer than 0.02 mm. is largely due to the greater percentage of colloidal-clay sizes present in various silt and glacial till soils. It should also be emphasized that the chemical composition of these clay sizes exert a great influence on ice segregation as we shall observe later in this essay. Thus, speaking in general terms, the test results available on this particular variable of frost heave concerning the general consensus that well-graded soils with less than 3 percent, by weight, finer than 0.02 mm. are not frost susceptible, has proven to be a useful rule but that other factors, such as the chemical characteristics of the fines must be considered in recognizing frost susceptible soils with accuracy or in predicting the intensity of ice segregation which may be expected under various roadway constructions or in soil layers.

(2) Tests On Effect Of Compaction

In a given soil, dry density (dry unit weight) is a soil property which may be used to study the combined effects of such physical soil characteristics as permeability, void size, and internal structure on ice segregation.

Increasing the dry unit weight of a soil by compaction decreases the void size but also decreases the permeability thereby controlling the rate of growth of ice lenses. The data rendered by the Frost Effect Laboratory, showed that frost heaving in silt soils increased with an increase in the original dry density and the same trend was indicated in experiments dealing with till soils. The most interesting result of these compaction tests is that there appears to be "one critical density" at which frost action occurs most readily, while at higher and lower densities the action is not so pronounced.⁸ Test results on effects of compaction by other soil mechanics engineers conclude that there appears to be one arrangement of the soil particles which might be called the "one critical density" that results in the most favourable combination of permeability and capillary action and encourages ice growth within the soil fabric.⁹ Although several theories have been suggested to explain the "one critical density" phenomenon it is quite evident that many additional tests are needed before final conclusions can be made concerning the effect of degree of compaction on percent frost heave. At the present time however, it can be asserted with certainty that percent heave may either increase or decrease with increase in original density and the effect of density change may be small or large, depending upon the density range researched and the characteristics of the particular soil in question.

(3) Effect Of Size And Percent Stone On Frost Heave

It should be noted that the addition or extraction of even a small number of stones (2 to 4 inches in diameter) in even a small sample can affect considerably the designated overall percent, by weight, of sizes finer than 0.02 mm. The presence of stones in a soil gradation may reduce frost heave because of increased rate of frost penetration due to the higher thermal conductivity of rock, the smaller amount of volumetric and latent heat in the soil mass, the reduced overall permeability.¹⁰ Test results from cold room studies on specimens of sandy gravel demonstrated clearly that with increase in the maximum-sized stone from $\frac{1}{4}$ in. to 2 inches in diameter, a decrease in frost heave followed.¹¹ Other research works from different laboratory studies applied a reversed approach to the one mentioned above, and showed that progressive increase in percent frost heave accompanied decrease in maximum size and percentage of stone.¹²

(4) Penetration Of 32°F Temperature

It is common knowledge that in nature heat flows from the air to the soil when the air is the warmer and from the soil to the air when the air is the cooler. When the air temperature drops below the freezing point, frost penetrates the ground. The greater the drop in air temperature and the greater the thermal conductivity of the ground the faster the penetration occurs. The greater the specific heat of the soil the slower is the penetration of the frost, the thermal conductivity remaining constant.

The speed and depth of frost penetration in subgrades depend also on the heat characteristics of the pavement or other road surface and base course. In the cold-room laboratory, the rate of penetration of the 32°F temperature into the soil samples was obtained from daily temperature records. However, a peculiarity common to all specimens was noticed. The 32°F. temperature after progressing into the sample for a distance of 2 to 4 inches suddenly receded, generally from 1 to 2 inches before proceeding downward again. Regular recurrences of this phenomena and close check of temperature measuring equipment indicated that the temperature recession is the result of changes occurring within the soil specimen during the freezing process. It was concluded that this phenomenon was due to the release of latent heat of fusion when the soil moisture begins to freeze at the top of the sample as a result of some triggering action, after having become subcooled to below the normal freezing point. Another important observation was that heaving commenced only after the temperature recession had occurred.¹³

(5) Temperature Between Frozen And Unfrozen Soil

The freezing point of soil moisture in the various soils tested was obtained by determining the temperatures at the boundary of the frozen and unfrozen layers. These temperatures were obtained by interpolation between thermocouple readings taken immediately prior to removal of the samples from the cabinets at the completion of the tests. The temperature data indicated that soil moisture in the soils tested freezes at temperatures ranging from 29.1°F to 32°F, with the lower values occurring

in silty and clayey soils. One of the reasons why soil moisture will not freeze until temperatures below 32°F , have been reached particularly in clayey soils is that the nature of water next to an adsorption surface of clay is quite different than the water which is adjacent to a layer soil particle. This phenomenon will be illustrated in the following detailed account of the clay fractions in soils.

6) Special Reference To The Clay Fraction

Within the last 25 years the occurrences and properties of the clay-mineral components of soil materials and the characteristics of clay-mineral-water systems have been the subject of very many researches. A realization of the significant role that clay minerals play in every aspect of soil studies has brought on the development of a specialized study called, Clay Colloid Chemistry.¹⁴

It is generally agreed by almost all soil scientists, particularly in the field of Clay Colloid Chemistry, that most soil materials are composed essentially of extremely small, usually colloid sized, crystalline particles of one or more minerals that have been called "clay minerals". Some clay minerals are equidimensional and flake-shaped, others are elongate and lath- or needle-shaped, and some appear to be tabular. The surface of the clay minerals provides the major adsorption surface in soil materials, and the adsorption features towards water and various ions and organic molecules vary for the different clay minerals.

There are two factors regarding frost action in clay minerals particularly pertinent to a consideration of the influence of the clay minerals.

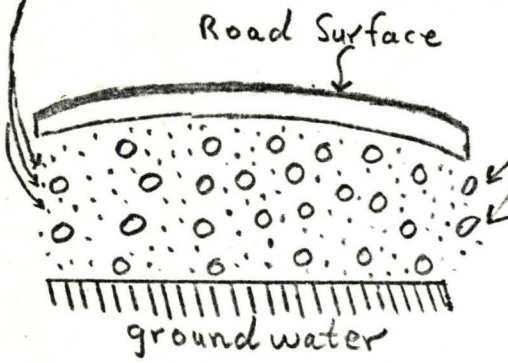
1. Taber's works has shown that frost heaving is due to the growth of ice crystals rather than to a volume change accompanying a change in state. An increase in the size of ice crystals requires that the growing crystal be fed by a supply of water, that is, there must be movement of water through the soil material. On freezing, soil material often shows segregation of ice masses into layers which require movement of water to the point of segregation. The growth of ice layers in very fine-grained soils such as the clays as far as I can ascertain, appears to depend upon mainly three physical facts:

1. Particles of capillary water contained in the larger soil pores freeze at either normal or slightly less than normal temperatures, say, $-1.$ to -4°C . ($30-23^{\circ}\text{F}$).
2. Particles of cohesive water contained in much smaller soil pores resist freezing at temperatures considerably lower than -4°C (23°F).
3. During the process of freezing, particles of capillary water attract from adjacent fine capillaries the films of cohesive water which individually do not freeze.¹⁶

Figure 5, 6, and 7 illustrate that when drawn into contact with existing ice crystals, the cohesive moisture changes to the capillary variety and freezes and thus increases the size of the existing crystals. Continuation of this process causes the ice crystals to increase in thickness as long as they are being supplied with either capillary or cohesive moisture through the fine capillaries from the ground-water supply below.

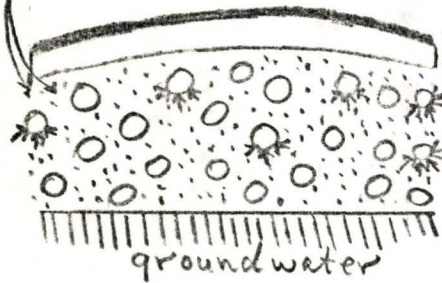
Small water particles do not freeze at normal freezing temperatures.

Larger water particles freeze at normal freezing temperatures.



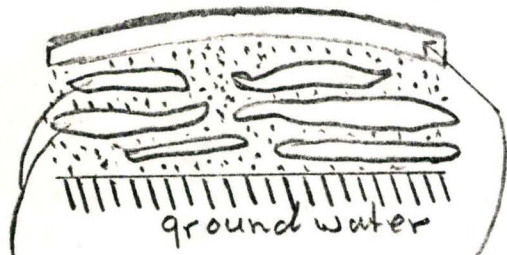
Small water particles freeze upon coming in contact with large water particles

Large water particles when freezing attract and grow at expense of small water particles.



M.B. Saturation vapour pressure over super-cooled water exceeds that over ice. Vapour moves in response to this pressure gradient.

M.S.H.
(Compare growth of ice-crystals at the expense of super-cooled water droplets in a cloud).



Ice layers due to continued growth of large water particles upon freezing

road surface heaved in amt. equal to at least the combined thickness of ice layers.

Figure 5. - Physics of frost heave

(taken from, C.A. Hogentogler — Engineering Properties of Soil)

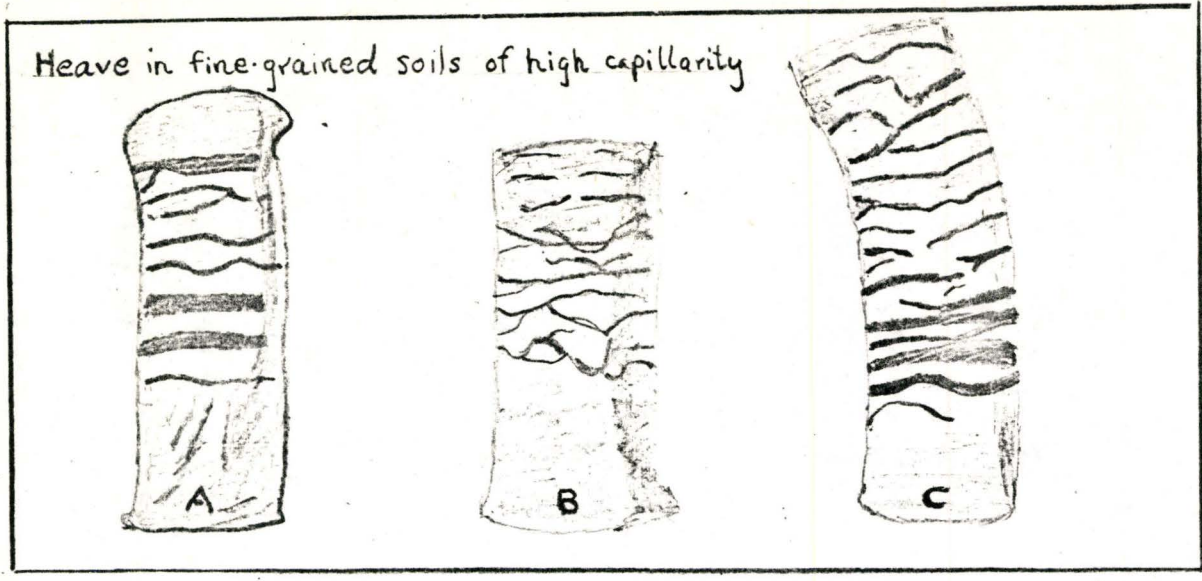


Figure 6. Ice lenses in frozen soil cylinders (sketch drawn by A. Poloniato from an actual photograph of ice lenses by Prof. Stephen Taber.)

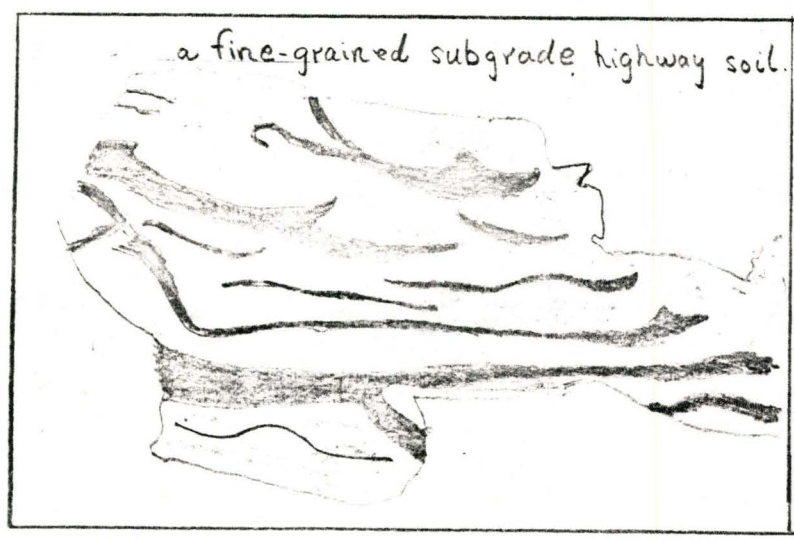


Figure 7. Ice lenses in soil from highway subgrade in Minnesota. (photograph by C.A. Hogentogler - Senior Engineer - sketch by G.A. Poloniato)

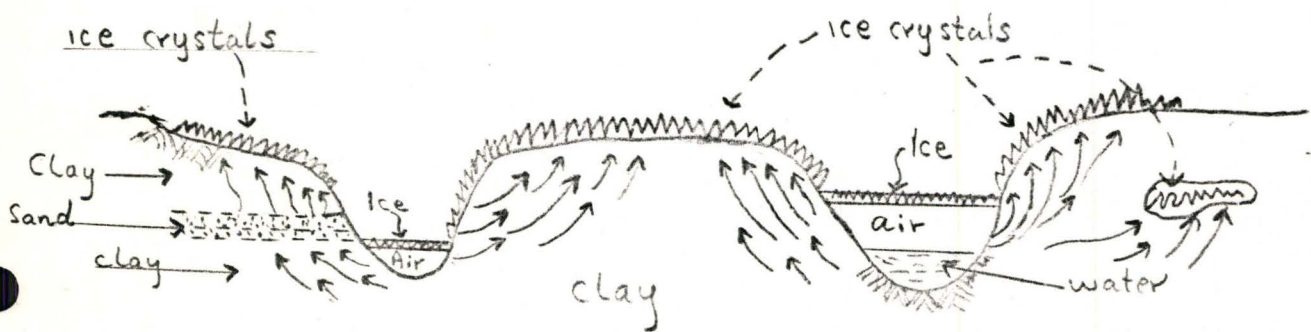


Figure 8. Water movements and ice formation on a rutted wet clay surface (taken from ACI - (American Concrete Institute - 219-67.) © C.A. Hogentogler.)

The force with which the frozen particles attract the unfrozen ones is according to Taber, and Grim, sufficient to lift a column of water almost 500 ft. in length.¹⁷ Water that forms crystals, however, may be drawn from any adjacent pocket as well as from the ground water. Figure 8, illustrates the occurrence of frost crystals and thin ice sheets frequently observed on clay roads that are more or less rutted. It has been observed both in laboratory controlled and field studies that ice crystals on the surface of clay soils will be longer than on those soils which contain less clay. Compacted clay soils will however, contain fewer frost crystals at the surface than a similar soil in a less compacted state.¹⁸ Intensive laboratory studies performed by Grim, Taber, and Hillel have clearly illustrated that capillary pressure varies inversely with the diameter of the pores. The frictional resistance to flow through a soil is a function of the surface area of the soil particles and consequently increases with a decrease in grain size at a much greater rate than does the capillary pressure. Therefore, it must follow that in order to supply capillary moisture in detrimental amounts, the pore size must be small enough to furnish appreciable capillary pressure, but large enough to prevent too much frictional resistance to flow.¹⁹

2. The second factor in which clay is very pertinent to frost

heave is one that students of agriculture soils have known for some time - that a certain percentage of water held by soils does not freeze at moderately low temperatures.²⁰ This phenomenon suggests that water held in soil pores of all sizes and in soils of all kinds may not all have the same characteristics.

Grim's well known laboratory and field studies have illustrated that water directly adjacent to an adsorption surface, that is to say, a clay mineral surface, in a soil is likely to be in a different physical state than the water in the centre of a fairly large pore. The two common but very different clay types of Montmorillonite and Illite is often used to exemplify this point.

In montmorillonite, adsorption water penetrates between the individual molecular layers, and as a consequence such material has tremendous adsorption surface and enormous water adsorption capacity. The theoretical total adsorption surface of montmorillonite is computed to be 800 sq. meters per gram.²¹ Many laboratory studies utilizing x-ray diffraction and electron microscope techniques have presented structural evidence that the water molecules adsorbed on montmorillonite surfaces show a crystalline configuration. In montmorillonite all the basal plane surfaces, which provide almost all the surface area, possess structural characteristics which seem to favour particularly the development of a crystalline configuration in the water molecules immediately adjacent to it, therefore the soil water would be held by the montmorillonite clay and not be fluid or mobile. Grim, has offered convincing evidence that the water initially adsorbed is rigid rather than mobile or

fluid and that at varying distances from the adsorbed surface the rigid water changes to liquid water. Figure 9, represents a diagrammatic sketch of the condition of the water in the plastic and non-plastic states.²²

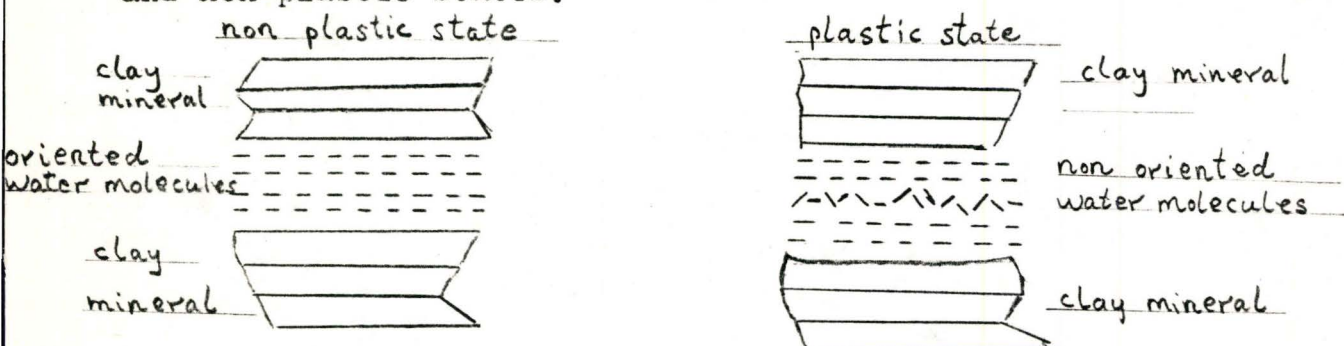


Figure 9. Diagrammatic sketch of the character of the water in the plastic and non-plastic states. (taken from Grim-Relation of Clay Minerals to Frost Action.)

Montmorillonite has high adsorption for certain cations, anions, and organic molecules. These adsorbed ions are held on the adsorbing water surfaces. The extremely significant fact is that the character of the adsorbed ion to a very considerable degree controls the perfection of the configuration of the water molecules and the thickness of the water layers, and as a consequence exerts an enormous influence on the properties of clay-water systems and hence on frost development.

In Ontario and in the New England States, the most common clay mineral found by far, is illite. See figure 10, for the approximate percentages of different clay types in soils of Ontario and New England. Illite soils contain adsorption surfaces which have a structure configuration likely to foster the development of orientation in adjacent water molecules. Somewhat more adsorbed water would be immobilized in illite clays than in kaolinite clay, but the total quantity would still be relatively small as compared to montmorillonite clays.

soil Profile

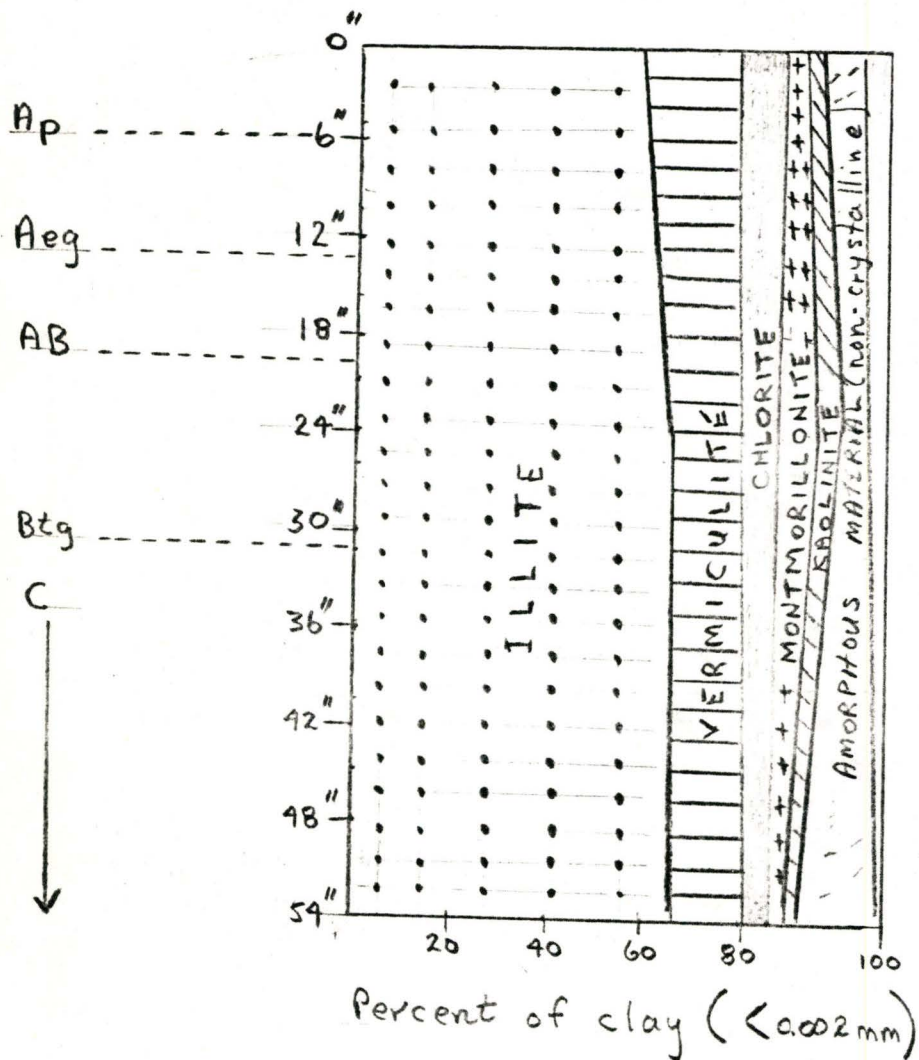
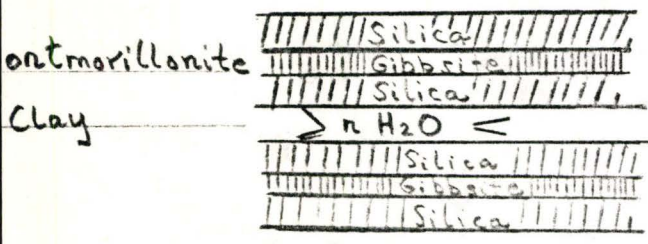


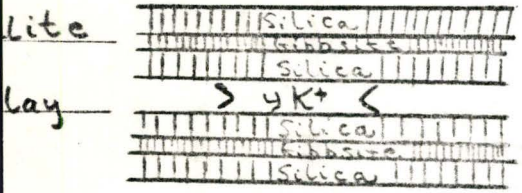
Figure 10. Mineralogy expressed as a percentage of the 2μ clay fraction in relation to depth in the Gleyed Gray-Brown Podzolic Soils of S. Ontario. (St. Lawrence Seaway Lab. analysis represented diagrammatically by G.A. Poloniato.)

As a result, at relatively low water content illite clays would be expected to contain fluid water. Illite clays are not impervious and show readily the concentration of water in ice layers upon freezing.²³

Soil materials composed of illite clay-minerals have an ion exchange of only about $\frac{1}{4}$ to $\frac{1}{2}$ that of montmorillonite soils. This phenomenon is due to a large degree to the geologic age of the soil and in the manner in which soil weathers. It must be remembered that the soils of Ontario and of the New England region are approximately 15 to 20,000 years old, being influenced to a great extent by a recent glaciation period, the Wisconsin.²⁴ Therefore, the weathering factors have not had the time required to enable the sequential development of illite clay to the montmorillonite type.²⁵ Figure 11, illustrates the difference between illite and montmorillonite clays.



Montmorillonite ($Al_2O_3 \cdot 5SiO_2 \cdot 5.7H_2O$) is hydrous aluminum silicate, the crystals are formed of silica & gibbsite layers. In montmorillonite, each gibbsite layer lies between two silica layers leaving contact surfaces between the silica layers as shown in fig. 11. The negatively charged surface of the silica layers attract water which occupies the space between silica layers in varying amounts. The spacing between the elemental silica-gibbsite-silica sheets depend upon the amt. of H₂O available to occupy the space. For this reason it is said to have expanded lattice as opposed to a fixed lattice of illite & kaolinite. Under some conditions, enough water may be present to separate the montmorillonite into ultimate platelets, hereby making montmorillonite a great adsorber of water.



Illite is similar to montmorillonite, except that the adjacent silica layers are bonded with Potassium ions instead of water. Potassium ions bear positive charges which bond the two negative surfaces of the silica layers. Because of the stronger cation bond of illite than the water bond of montmorillonite, the tendency for forming ultimate platelets is less than for montmorillonite. Thus, illite does not have the capacity for adsorping water as montmorillonite clays, and therefore becomes saturated rather quickly.

Figure 11. (taken from M.L. Jackson & Means & Parcher)

The influence of various cations in illite would be expected to be less than that for montmorillonite, but considerably more than that for kaolinite. Many illite soils contain small amounts of montmorillonite interlaminated with the illite layers. These small amounts of montmorillonite can have an effect on physical properties out of all proportion to the amount actually present. This conclusion should also apply to frost action. A small amount of montmorillonite would greatly increase the amount of water immobilized particularly if adsorbed sodium ions were present and as a result increase the impermeability and decrease the tendency for water to concentrate in ice layers upon freezing, as previously shown in figures 6 and 7.²⁶

CONCLUSION

It should be emphasized that laboratory-controlled studies can only simulate natural field condition to a certain degree. In recent years, particularly in the studies of soil physics and clay colloid chemistry, laboratory techniques have developed to a very high state of sophistication. But even when considering these technical advancements, the most serious students of soil sciences admit that they can, at best only approximate the natural environment. Many laboratory-controlled studies have been rather successful in explaining quantitatively and qualitatively the variables influencing frost action phenomena in various soils. On the other hand, many researchers have had to disclose the fact that much more testing and instrumentation improvement must be incorporated into their analyses before any satisfactory answers can be displayed. A study of frost-action in soils soon reveals to

the soil student that there appears to be a variety of operations and processes working simultaneously within the soil, both outside and within the soil that influence such a phenomenon. Thus the laboratory approach becomes only one kind of a means by which the frost action phenomenon can be understood.

Footnotes

1. Cold-room studies of frost action in soils are being performed by the Frost Effects Laboratory, New England Division, Corps of Engineers, Dept. of the Army, U.S.A., Special Report Symposium #2, 1952, and Soils Engineering Journal XXIV, 1968, and by the National Research Council, Associate Committee On Soil and Snow Mechanics, Canada.
2. Being that variable #6, involves frost action in the clay fraction, it will be discussed in considerable detail in the latter half of this paper.
3. Properties of Vermiculites can be studied in Zim and Shaffer's book, Rocks and Minerals, 1967, p.96, and H. Van Olphen, Clay Colloidal Chemistry, 1963, p.69.
4. The molecular structure of glycerin is such that it adopts itself to temperature changes very readily. The molecular structure of glycerin is responsible to a large degree for both its tensile and shear strengths which offer very little resistance to temperature changes. Secondly, glycerin has a very low specific heat factor which enables this liquid to lose or gain heat very quickly, hence a more accurate temperature average value can be ascertained at any given time.
H. Van Olphen, pp. 133-135
Means and Parcher, pp.128-130
Helmut Kohnke, pp. 16-17
Chemistry and Physics Handbook, p.603
5. Within the past 25 years, a period of 24 to 28 days has been found to be the standard time set for most accurate results in soil and concrete testing. A 28 day duration period is now actually stipulated in ASTM and in ACI, concerning Soil Mechanics and Concrete Technology Specifications.
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