Soil Mound Formation by Multicyclic Freeze-Thaw

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Abstract

Experiments are being carried in freezing cabinets in order to determine the effect of many cycles of freezing and thawing in a layered soil 4 cm thick. The soil was composed of three horizontal layers, two layers of silty-clay and a layer of crushed quartz in between; each layer was 1.3 cm thick.

Moisture was supplied from the bottom and thawing from the top. Through the experiment the soil was saturated; average rate of freezing was 1 mm per hour, rate of thawing 2 mm per hour.

During the first 28 cycles only a broad mound was developed; after that small mounds 1–2 cm at the base started to form. The maximum height of mounds was 2 cm. The number of mounds reaching a certain height indicates that the rate of mound growth is higher through cycles 28–37; after that the rate of growth decreased.

The form of the mounds is not upright cone; they are inclined and near the top the material is inclined to horizontal.

It is proposed as a very qualitative approach that these mounds are produced by the release of pressure during freezing. Pressure is released in the freezing layer in loci with the highest percentage of unfrozen water. To such places of unfrozen water the migration of particles and water takes place.

The extrusion of particles at the upper part of the mound is an indication of such migration.

It is believed that this is the first report on experimental formation of soil mounds.

I. Introduction

Not very much experimental information is available on the frost behavior of soils for many cycles of freezing and thawing. According to the author experience (Corte, 1962 a, 1962 b) for certain soils one cycle is not enough to obtain the needed information. As it will be shown, during freezing and thawing cycles certain soils are subjected to changes which are affecting the soil. Since these changes are not reversible the soil will behave differentially under every freezing and thawing cycle. Therefore an important question is: How many cycles a soil should be subjected in order to obtain a representative frost behavior pattern?

Reports on frost action are concerned with mounds formation in the field. Such mounds have been treated by different authors; the large ones up to 40 m high are called hydrolaccolithes or pingos (Porsild and others, 1938). Such mounds have cracks produced by the release of internal pressure; the cracked upper layer is believed to be solidly frozen. The smaller mounds with sizes varying from a few centimeter up to 1.50 m are called frost mounds (Kushev, 1939; Mordvinov, 1940 and others according to Kachurin, 1964). The origin of the large mounds is well understood while the origin of the smaller ones is uncertain. The formation of convoluted, contorted or disturbed soil layers is also considered as another feature of frost action effects. We do not have actual experimental information showing how this deformation is produced. It is reasonable to assume that the two frost effects: Mound formation and convoluted or contorted layers must be related.

In order to get some information on this matter a horizontal layer of crushed quartz was placed between two horizontal layers of silty-clay and subjected to many cycles of freezing and thawing. This is a progress report on this research which is still going on.

II. Experimental Procedure

Freezing cabinets, and soil samples. Tests were performed in small freezing cabinets of the same type used for storing food; interior sizes are: 0.75 wide 1.00 high and 1.20 long in meters. Sample holders used are commercial type of plastic pans 31.5 long, 24.5 wide and 10.0 high in centimeter; wall thickness 5 mm.

In order to produce unidirectional freezing and thawing the pans were insulated with a plastic foam 20 mm thick commercially known as "tergopol" (Fig. 1).

The sample of silty-clay was obtained from a loose exposure; grain size analysis indicate that they are composed of a small percentage of fine sand, the remaining half silt and the other half clay fraction. The sample of crushed quartz was obtained from a quarry from which different grain sizes can be obtained. It is composed mostly of sand fraction with some silty-clay fraction. The samples were laid in even surfaces with

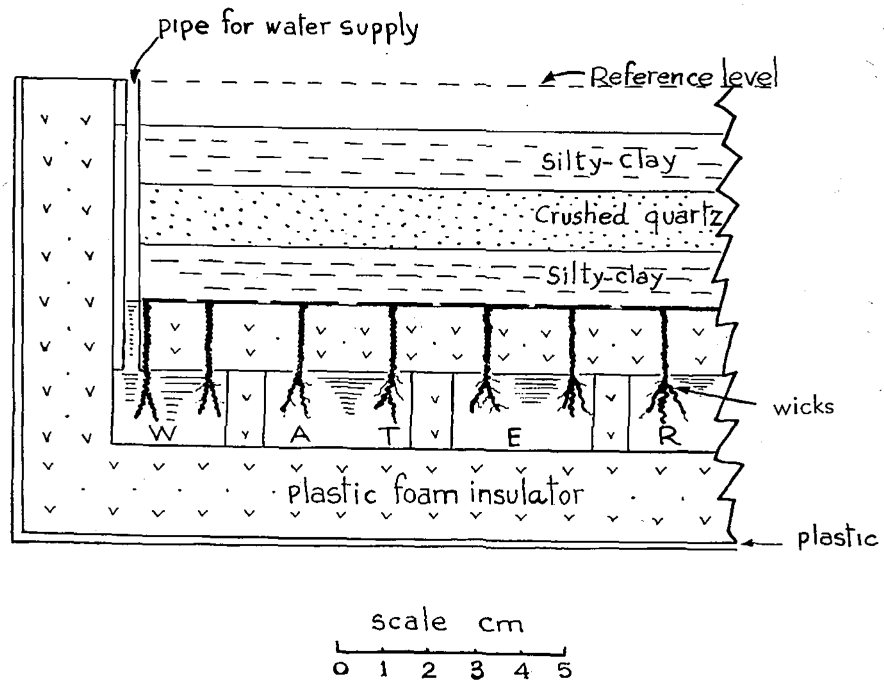

Fig. 1. Cross section of freezing pans showing location of soil layers before freezing. Reference level on top is the reference line to which mounds reached

layers of 1.3 cm thick (Fig. 1).

Moisture was supplied by means of wicks hanging from the bottom of the soil through a tergopol layer to a water storage tank. This storage tank was also insulated so that moisture conduction to the soil during freezing was ensured (Fig. 1). In order to produce a uniform moisture supply the amount of water was maintained constant by weighing the whole freezing pan.

Freezing and thawing conditions and rates were determined by eye inspection using a blank test. Such test was sectioned at different times in such a way that the frost line penetration was determined; the same thing was done for the thawing stage. With the freezing cabinet at $-5°C$ it was determined that the rate of freezing line penetration was about 1 mm per hour. The thawing was accomplished by taking the freezing pans out of the cabinet and the rate of thawing was about 2 mm per hour. Therefore the minimum temperature of the soil was never below that of the freezing cabinet *i.e.* $-5°C$.

III. Experimental Results

During freezing and thawing cycles it was observed that the soil heaved and sunk continuously. Maximum heaving during the first cycles before mound development was about 10 mm; that is 30% volume increase. Maximum heaving in mounds was 7.0 mm or 24% volume increase.

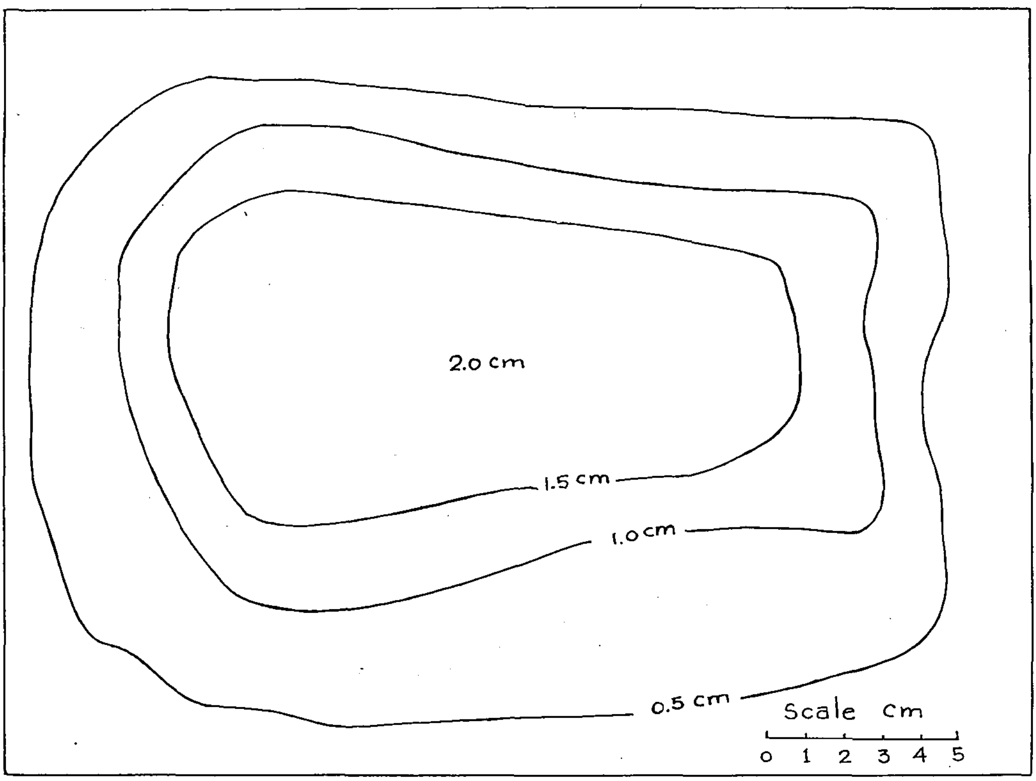

Fig. 2. Top view of experiment after cycle 20 showing development of one single mound 2 cm high

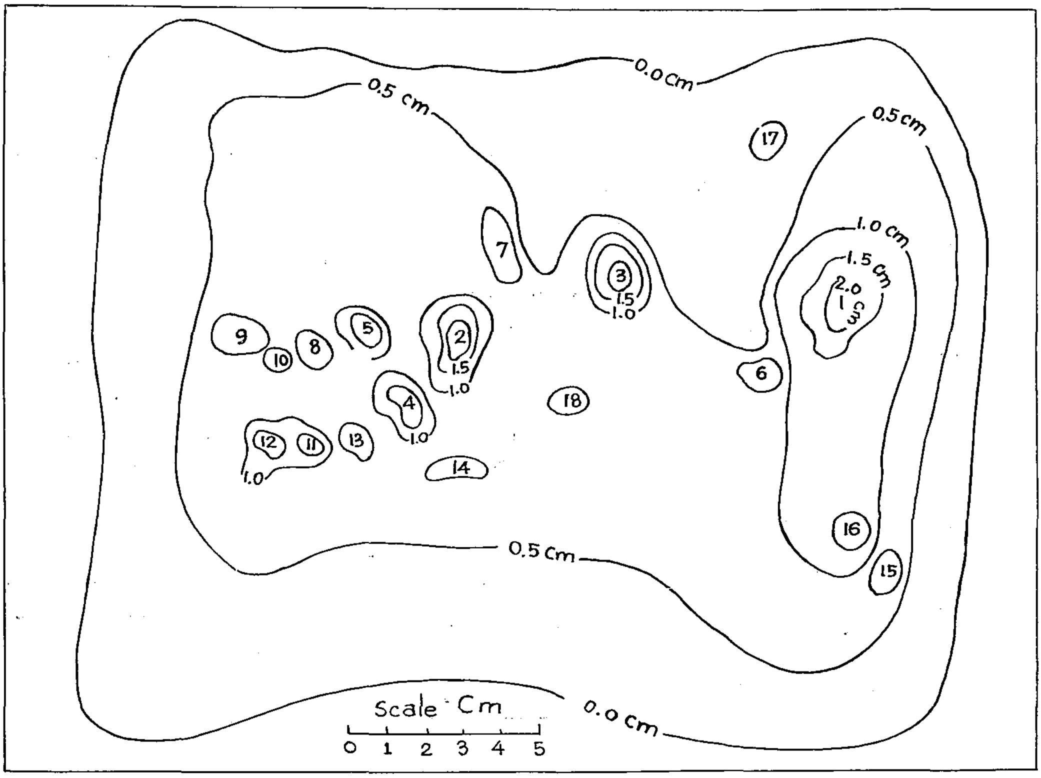

Fig. 3. Top view of experiment after cycle 33 showing development of 18 mounds. Maximum height of mounds is 2 cm. Numbers in center of circles are mound number

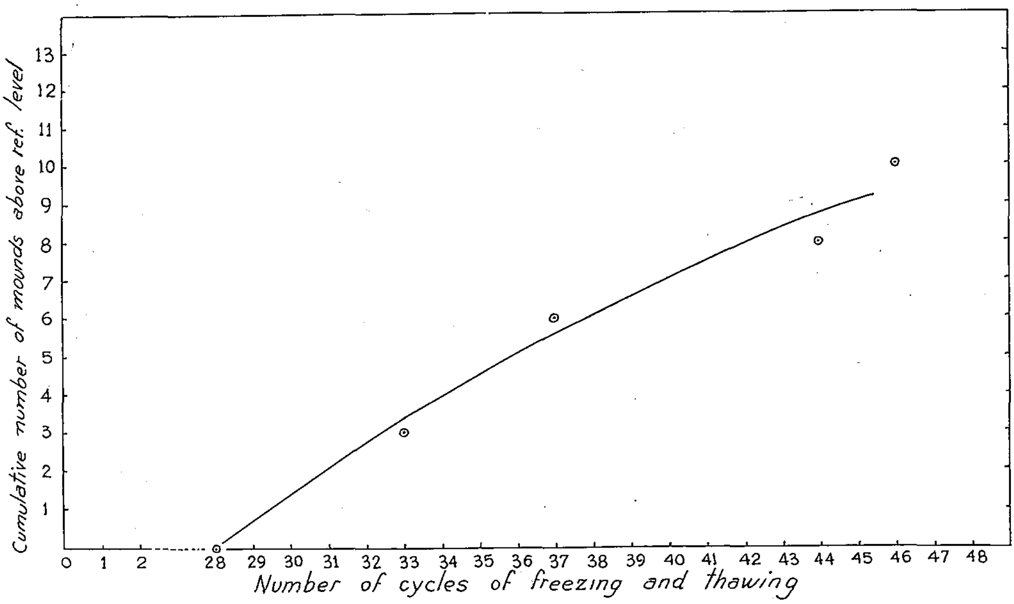

Fig. 4. Number of mounds reaching reference level as a function of the number of the freezing and thawing cycles

In a general view of the experiment two stages can be differentiated: First stage covering cycle 1 to 28 in which a broad mound is developed (Fig. 2), and second stage from cycle 28 to 47 in which some 18 mounds formed in the area covered by the previous large mound (Fig. 3).

According to the records the rate of growth of some mounds was estimated to be of the order of 1 mm per cycle. Measurements were taken of the number of mounds reaching a certain elevation, which is called reference level in Fig. 1. From cycle 28 to 37 there is a higher rate of mound growth than after cycle 37 (Fig. 4).

During the formation of mounds it was observed that no cracks was developed. This indicates that the dome formation in the silty-clay is not produced in the frozen stage but in a partially frozen condition. It is also observed that concurrently with the formation of mounds there is extrusion of crushed quartz from underneath. Regarding the form of the mounds, it is observed that in general they are not like a cone. They are generally inclined with the top side hanging to one side (Fig. 5).

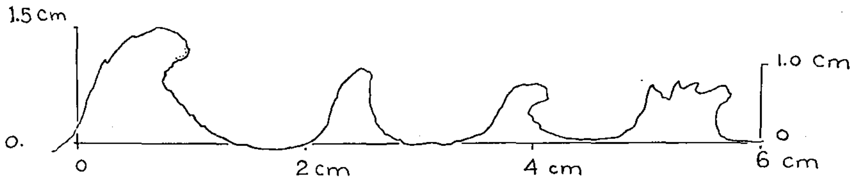

Fig. 5. Cross section of mounds 2–5, 8, 9 and 10 shown in Fig. 3

IV. Interpretation of Results

At the present stage of this experiment it is possible only to offer a very qualitative approach to the problem of mound formation. Further experiments will be necessary for a much closer approach.

Regarding the origin of the mounds, the author feels that the amount of unfrozen water in a frozen layer must be important in this process. When the upper silty-clay layer is frozen and the crushed quartz sand began to freeze there must be a release of hydrostatic pressure through the upper layer. The places more likely to yield to the pressure are the areas with the highest content of unfrozen water; through such places will migrate water and soil particles. In support of this theory we can use two lines of research: The work performed by Tsytovich (1964, chapter V) and others which shows that the amount of unfrozen water in frozen soils depends on the grain size, mineralogical composition and temperature below freezing. The amount of unfrozen water increases as the grain size decreases. Montmorillonitic clays have the highest amount of unfrozen water. The other line of research shows that there is a migration of water and particles in front of a moving freezing front. Kachurin (1964, chapter IX) indicates that the migration of water and "slurry" has been confirmed by the field work of Popov (1953) and Bakulin (1958). Also it is indicated that under favorable conditions fine grained slurry penetrates into layers of more porous and coarse grained soils. An experimental demonstration indicating the roll of the different variables affecting the migration of particles in front of a moving freezing plane has been presented by Corte (1962 c).

In summary, it is proposed that an unfrozen area in a freezing layer becomes a place of particles and water concentration with the consequence of the formation of a mound.

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