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A REPORT ON PERMAFROST SURVEYING

(MANCHURIA, 1943)

by

Ukichirō Nakaya and Jūji Sugaya

中谷宇吉郎、菅谷重二

from

Teion-Kagaku, 2, (1949), 119-128

translated by

E. R. Hope

This is the seventeenth in the series of translations prepared for the Division of Building Research

OTTAWA

1953

PREFACE

The Division of Building Research of the National Research Council is keenly interested in permafrost research, having now its own Permafrost Research Station at Norman Wells, N.W.T. Contact is maintained with the Snow, Ice and Permafrost Research Establishment of the U. S. Department of Defence in connection with this work and allied snow and ice research.

Through this liaison, it was possible for officers of the Division to meet again with Dr. U. Nakaya of Japan, who is spending some time as a guest worker with SIPRE. It was thus found that Dr. Nakaya, in addition to his world-famous snow studies, had carried out some field investigations of permafrost in Manchuria in 1943. Dr. Nakaya kindly made available a copy of his paper on this work.

With the co-operation of the Defence Research Board, through the Defence Scientific Information Service, it proved possible to have this paper translated from the Japanese. The translation was carried out by Mr. E. R. Hope of the D.R.B. staff. Mimeographed copies were prepared by the Defence Research Board. It is this translation which it is now the privilege of the Council to publish in this form.

Not only does the publication represent co-operation between these two Canadian agencies but it is a pleasure to state also that the translation was not only approved by Dr. Nakaya but carefully checked by him and, in view of its excellence, adopted as the translation to be used by the SIPRE organization.

Appreciation is here recorded of the translation by Mr. Hope, and the co-operation of Defence Research Board in this work, and to Dr. Nakaya for making the original paper available for translation and for his continued interest in its preparation.

May, 1953.
Ottawa, Ontario.

R.F. Legget,
Director.

Translated from Teion-Kagaku, 2, (1949), 119-128.

A Report on PERMAFROST SURVEYING (Manchuria, 1943)

by

Ukichirō NAKAYA and Juji SUGAYA

Hokkaidō University Low Temperature Research Institute.

Research Report No. 33.

§1. ARGUMENT

In engineering jobs undertaken in the permafrost zone, the solidity of foundations will depend on whether or not the frozen earth of the upper part of the frost-table has sufficient hardness. Hence in these regions the precise determination of the distribution of ground temperatures in the frost-table, at the beginning of autumn when the active layer has melted down to its lowest level, is an important matter. From the results which we have obtained in an investigation of frost-heaving phenomena, it appears that the ground temperature, though it may be below zero Centigrade, is however never very far from zero. Accordingly we constructed thermocouples capable of measuring ground temperatures in the neighborhood of 0°C with an accuracy of 0.01°. Using these thermocouples, we carried out precise ground temperature measurements in the T'ien-Ni-Ho * Engineering District in North Manchuria, during the last ten days of September 1943. We are here reporting briefly on our results, and on the characteristics of the soil in this zone.

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* 天泥河, near Hailar. The "Engineering District" refers to the Manchurian Railway. (Translator.)

§2. APPARATUS FOR MEASURING GROUND TEMPERATURES

In permafrost localities it is quite impossible to dig deep holes in the frozen soil during the thaw period. This region is the zone of the so-called "black earth", which turns to a sea of soft mud; the sides of the hole will cave in, and there is no way of preventing it. We decided to get our ground-temperature measurements by driving a long iron rod into the permafrost and forcing long thermocouples into the hole which this rod left after its removal.

Our thermocouples were made of a copper wire and a constantan wire, each 13 meters long and 0.55 mm in diameter. They were fitted with a protecting tip as shown in Fig.1. A small hole was bored through the compound brass-and-ebonite rod to take the thermocouple. The purpose of the ebonite was to provide thermal insulation for the electrical leads. The protector-tip had a diameter of 14 mm, and was brought to a sharp point as in the illustration. The insulation of the thermocouple wires was enamel plus a double winding of silk. The two wires together were overlaid with a sheathing of cotton tape and the whole dipped in melted paraffin. The thermocouple thus insulated was inserted into the hole in the brass tip, and oil was poured down into the bottom of the hole in order to ensure good thermal contact with the protecting rod. To the rear end of the protector-tip there was attached a piano wire 7 m long and 2.7 mm in diameter, which ran alongside the thermocouple leads. The piano wire and leads were wrapped in several thicknesses of insulating material plus a waterproof covering; then over this a tight winding of 0.7 mm iron wire. Made in this way, the device can be coiled up for carrying; when extended, the stiffness of the piano wire is sufficient to enable it to be thrust deep into the frozen ground. We constructed two of these instruments, which we designated as No.1 and No.2.

It was necessary to calibrate the instrument precisely for the zero point, for which purpose we used a thermos flask in a double-walled ice-water tub, constructed as shown in Fig.2. Testing with this apparatus showed that the error in our measured temperatures was less than 0.01°C, which was quite satisfactory for our purposes. The galvanometer used was a precision model of Riken * manufacture, having a sensitivity of 1.0×10^{-7} v, 10^{-10} A. As the resistance of the thermocouple and its leads amounted to 30 ohms, it was easy to adjust the sensitivity by a precision rheostat inserted in the circuit and to raise the sensitivity in the neighborhood

* The Riken Keiki Kabushiki Kaisha. (Translator.)

of $0^{o}C$ to as much as 100 mm of swing per degree C. For measuring comparatively higher temperatures we used a reduced sensitivity, one-half to one-fifth of this.

For drilling holes in the permafrost, we constructed and carried with us the gear shown in Fig.3, (a) (b) and (c). In Fig.3 (a), R is a steel rod 16 mm in diameter, to the end of which drill-bits are attached as shown at (c) in Fig.3. P_1 and P_2 are stops, which may, when the handle is loosened, be freely moved to any position and firmly locked in place. H is a hammer, which is struck by hand against the lower stop P_2 to drive the steel into the ground, and against the upper stop P_1 to withdraw it. The length of each steel is 1.5 m, and by using several of them joined together sectionally, it was possible to get temperature-measurements at depths of as much as 6 m.

We used two sets of drills. As soon as a hole was drilled, one of the thermocouples was immediately inserted in it, and ground-temperature readings taken every other minute for a period of 20~40 minutes, until it was certain that a steady temperature had been reached. Meanwhile the other drill was being driven in, and so on alternately.

The galvanometer was installed on top of a 12-cm-square wooden post driven into the earth to a depth of 80 cm. This galvanometer stand and all of the measuring equipment were set up inside a shelter-tent.

Thus equipped, we were in a position to expect an accuracy of $0.01^{o}C$ in our field-survey work on ground-temperatures.

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§3. CONDITIONS AT SURVEY SITE

At the survey site the ground sloped away to the ENE at about a 6^{o} angle for about 200 m, with its lower edge abutting on a river-bed flat. We were at a height of about 22 m above this flat. The ground was covered with wild graminaceous grasses, growing to a height of 30~40 cm.

The soil from the surface to a depth of about 60 cm was a black humus. For the next 30 cm below this level, there was a brownish black layer of clay with a content of humus, and below 150 cm a layer of brown-colored clay practically devoid of humus and containing an occasional pebble. Of course these different layers were not sharply demarcated;

the change in the soil was continuous. The humus top-soil represents what is called " black earth" in this region, the "black earth zone". The ignition loss of this soil was determined, and was found to be small, not exceeding 11.0% of the weight of the wind-dried soil; in other words, the residual ash content was 89.0%. Thus, even in this black top-soil the actual content of humus was found to be unusually low. A diagram of the vertical section of the soil is shown in Fig.4. The thaw-layer, at the time of making the measurements, extended to about 2 to 2.10 meters below the surface, and it is believed that this was the season of deepest thawing. Samples were taken from the points marked 1, 2, 3 ... 11 in Fig.4; their water contents and apparent specific gravities were determined, and a grain analysis made.

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§4. GROUND-TEMPERATURE MEASUREMENTS

i) Progress of the Measurements.

Two days were spent in constructing the shelter-tent, manufacturing distilled-water ice, and calibrating the thermocouples. On the third day, we commenced boring holes with the above-mentioned drilling gear and taking measurements. At depths less than 2 m, the bore clogged up by earth-pressure as soon as the drill was withdrawn, and the thermocouples could not be inserted. We decided to excavate the thaw-layer to a depth of 1.8 m and drive a two-inch iron pipe down into the frost-layer, thus preventing the surrounding thawed soil from squeezing in. Then we started to drill from inside this pipe. Even so, there was some soil-pressure, as the top part of the permafrost layer itself was close to a thawed condition. The result was that when we finished taking our observations and attempted to pull out the thermocouples, one of them broke.

After this we decided to remove the thaw-layer completely, until the face of the frost-layer was exposed. We left a 30 cm projection of frozen earth, with a slight hollow dug out around it to collect the thaw-water which ran in from the surrounding walls, so that the flat top of the projection was always above the water surface. Our holes were now bored starting from this flat top. The pit dug to lay bare the surface of the permafrost measured about 2 x 3 m. Since the lower half of the thaw-layer had a water content which brought it near to the fluid state, the walls kept caving in while we were digging, which made the work very difficult. By using retaining boards, we got the job done, but one of the authors (Sugaya) and eight laborers had to spend almost the whole day on it. Next morning, half of the pit had caved in, so that we were faced with another day's work to dig it out again. On the fifth day, however, we were able to complete our temperature measurements at depths of up to 4.87 m. Then we called it quits.

ii) Results of ground-temperature measurements.

Results of our ground-temperature measurements are shown in Table I and at (a) in Fig.5. The solid line in Fig.5 (a) represents measurements made with the thermocouples. The thick broken line is thermometer measurements of the temperature in the thaw-layer, as explained in paragraph iii. The finer broken line represents thermometer measurements made inside an iron pipe set in the ground, as will be explained in paragraph iv.

TABLE I

Measurement No.	Time of measurement		Depth	Ground temperature	Remarks
1	Nov.24,	1050	53cm	+3.06°C	Air temperature +5°C.
2		1137	101	+2.73	Wind velocity 10 m, measurement difficult.
3		1240	160	+1.56	
4		1340	192	+0.42	
5		1509	270	-0.10	Light rain falling.
6		1630	229	-0.04	
7		1800	56	+3.42	
8		-	12	+4.00	Air temperature 9°C, wind speed 13~15 m.
9	Nov.26,	1015	211	-0.02	
10		1408	300	-0.23	Hole bored inside iron pipe.
11		1813	404	-0.40	
12	Nov.27,	1900	324	-0.33	Thaw-layer removed.
13	Nov.28,	2000	487	-0.44	Thaw-layer removed.

In Fig.5, the [horizontal] 0°C line is taken from the measurements, while the "frost" line was determined by examining the excavation. This frost-line was at a depth of 210 cm, which would seem to be the value for the time of lowest penetration of the active layer in this region. At the season when the present measurements were taken, the mean air-temperature had already dropped to 0°C, and since the thaw-water flowing in a small gully in the same sloping ground as our site had markedly diminished in volume during the previous week, it seems that the thawing of the frost-layer had practically ceased.

The temperature in the frost-layer was quite near to 0°C. In the top 75 cm of the layer, it stayed above the limit -0.1°C. This was obviously to be expected from the results of our research on frost-heaving during the thaw-season.* At greater depths, the ground temperature fell to minus 0.3~0.4°C. Between 3 m and 5 m depth, precise measurements showed that the rate of fall was about 0.10°C/m. Thus we may take it as established by the present research that the temperature in the upper part of the permafrost layer at the end of the thaw-season is close to 0°C, and that it remains above -0.4°C down to a depth of several meters.

iii) Temperature-distribution in the thaw-layer.

When excavating on the 27th, we determined the temperature distribution in the thaw-layer by inserting a straight thermometer horizontally into the earth to a depth of 30 cm at various depths in the ground cross-section. The results are given in Table II, and as shown by the thick broken line at (a) in Fig.5, the values are highest at a depth of about 60 cm. The distribution is in good agreement with the temperatures measured inside an iron pipe, as shown by the fine broken line in the same figure. On each of the two days in question the weather was good, the atmospheric temperature rising to above 11°C in the day-time and showing about the same diurnal variation. This undoubtedly contributed to the agreement between the two curves. The above values show a difference of 1.5°C as compared with those found with the thermocouples on the 25th. The reason is that on the 25th and previous days the weather had been continuing cold, with a light rain falling from time to time.

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* Nakatani and Sugaya, Teion Kagaku, Vol. 2, p.7.

TABLE II

Depth in cm.	Ground temp. °C.
10	3.7
30	4.7
50	5.2
70	5.2
90	4.4
110	4.0
130	3.8
150	2.7
170	2.1
190	1.3
210	0.0
230	-0.2

To determine the coefficient of thermal diffusion in the thaw-layer, we made a series of temperature measurements at the ground surface and at depths of 10 and 20 cm. (These measurements were handled by Mr. S. Nakayama, who accompanied us on the expedition.) The results are as in Fig. 6. The amplitude-decrease and phase-shift both show up very well. From these results, let us try to extract the value of k in the thermal diffusion equation

$$\frac{\partial \varphi}{\partial t} = k\frac{\partial^2 \delta}{\partial x^2};$$

that is, the coefficient of thermal diffusion.* For sine-curve boundary-conditions, the solution for k is well known; as found from the phase-shift ε it is

$$k_\varepsilon = \frac{\pi x^2}{T(\varepsilon_o - \varepsilon_x)^2}$$

* The equations below are slightly modified from those in the published text, this modification having been suggested by the authors of the paper. (Tr.)

and from the amplitude ratio:

$$k_a = \frac{\pi x^2}{T(\log \frac{A_o}{A_x})^2}$$

For a sine curve, $k_\varepsilon = k_a$, but since in natural phenomena there is generally a small departure from the sinusoid form of variation, the two values do not agree. In order to reduce the labor of determining α for each of the elementary curves obtained by harmonic analysis, we took the curves of Fig.6 as roughly sine-curves. Putting $\varepsilon_o - \varepsilon_x = 2\pi \times \frac{3}{24}, \frac{A}{A_x} = \frac{86}{32}$, $T = 24 \times 60 \times 60$ sec, we find

$$k_\varepsilon = 0.006, \quad k_a = 0.004$$

The mean is $k = 0.005$.

This value is rather large compared with k for ordinary soil, which is about 0.003 ~ 0.002, but as the thermal diffusion coefficient of a "black earth" soil nearly saturated with water, it is more or less a value which is to be expected.

iv) <u>Earth temperature measurements, using a pipe set in the ground.</u>

For purposes of determining the ground-temperature distribution in the permafrost stratum, the Construction Office of the Manchurian Railway used to use 2.5-inch iron pipes set in the ground to various depths, inside which temperature observations were made each day at 10 a.m. On comparing the temperatures thus recorded for the 28th with our thermocouple readings, we detected a systematic difference. When the thermometers used were calibrated to 0°C with distilled water and ice, they were found to have an error of maximum value +0.6°C. Correction for this error gave values as in Table III. When plotted at (a), (b) in Fig.5, these values formed a curve of shape quite similar to that of the thermocouple measurements, but on the whole they were 0.2~3°C lower. We have not obtained sufficient data to establish the cause of the discrepancy, but the fact does appear that the pipe method, with this small error, gives unexpectedly accurate results.

TABLE III

Depth	Measured values	Correction	Adjusted values	
0.1 m	+2.5°C	+0.4°C	+2.9°C	wooden pipe
0.5	+4.6	+0.5	+5.1	
1	+4.6	+0.1	+4.7	
2	+1.4	0.0	+1.4	
3	-1.0	+0.6	-0.4	
4	-0.7	0.0	-0.7	
5	-1.0	+0.4	-0.6	Iron pipe
6	-1.0	+0.05	-0.9	
7	-1.3	+0.4	-0.9	
8	-1.4	+0.6	-0.8	
9	-0.8	+0.1	-0.7	
10	-1.4	+0.6	-0.8	

§5. CHARACTER OF THE SOIL IN THE THAW-LAYER AND IN THE FROST-LAYER

i) Relative water-content and mode of congelation.

The water-content and apparent specific gravity were measured for the eleven samples taken as shown in Fig.4. Table IV gives the results.

Upon examining the specific gravities and water-contents in the thaw-layer, we see that the black top-soil in the neighborhood of sample No.1 is rich in humus, and therefore has a low specific gravity. The water content appears to be remarkably high. Even so, the figure in the Table, 0.39, is not yet at the point of stauration, and the soil looks as though it were comparatively dry. For the brownish-black argillaceous soil of sample No.2, which still contains some humus, and for the brown clay of sample No.3, the saturated water-content is below 0.35, and the figures in the table, as we shall later explain, represent water-contents close to the run-out point.

In the frost-layer, there seems to be a scattered development of both fine ice-lenses and nodules, of which four examples are shown in Fig.7, (a) to (d). The first three, (a) to (c), are examples of the mode of congelation which is ordinarily seen in the permafrost of this region, while (d) is a more exceptional mode. At the place where (d) (that is, sample No.11) was taken, there was a local agglomeration of earth, about 30 cm^2 in area and about 15 cm deep, which displayed this type of freezing, namely one with an ice-layer distribution of the same form as the patchy freezing seen at places in Hokkaidō where there is frost-heaving. The difference is only that the ice-layers, made up of transparent ice, do not show any vertical striation of "frost-pillar" type. The striations, which give the appearance of pillars of frost, consist of fine columns of air and lines of air-bubbles. In the present case no such air-columns nor air-bubbles could be seen under the microscope. The reason for this is perhaps that ice which has formed with a frost-pillar structure loses its air-columns and air-bubbles after it has stood for months or years under pressure. This is a point which needs experimental verification. The ice-lenses ordinarily seen, as in Fig.7 (a) to (c), likewise consist of transparent ice and, from their shape, represent ice which has formed in cracks and crevices in the soil. Many of them are made up of small ice-particles welded together into lens shape. This mode of congelation resembles the distribution of ice-layers in frost-heaves in heavy clay soil. Ice nodules of considerable size are often seen. The soil between the ice-lenses is soft and half-thawed, but since it is tightly packed, it is as a whole fairly solid.

A grain analysis was made on the eleven samples of Table IV, results of which are shown in Table V. This table shows clearly the fact that the whole bed of soil has a very uniform composition of high argillaceous content. The vertical distribution of clay content, as extracted from Table V, is shown in Fig.8. The easily mobile part of the soil at depths of around 1 m shows a relative maximum of clay content, and in the frost-layer the clay content again increases with depth. If similar instances of this phenomenon are found at other places, we may conclude that when the active layer thaws, the fine particles wash down out of it, and that the lowest point to which the active layer has penetrated, over a long period of time, is at present buried in the frost-layer.

For the six samples taken from the frost-layer, the relation between the water content and clay content is as shown in Fig.9. The larger the clay content, the smaller the water content becomes. Now in ordinary soils, those with a high clay content have a proportionately high water content. But in ordinary frost-heaves, when the clay content in the soil is too high, it becomes relatively impermeable to water and the absorption from below is small; thus the water content tends to decrease. We think, then that since this frost-layer of ours is actually the upper part of the permafrost stratum, the fact that it is the same in character as a frost-heave does give us some information on the origin of the permafrost body.

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ii) <u>Estimate of the amount of frost-heaving.</u>

Since from the above results it could be deduced that frost-heaving phenomena very likely occur in the permafrost stratum, we attempted an estimate of the amount of this frost-heaving. To obtain the necessary data for this purpose, we mixed samples 5 to 11. That is, we investigated the average properties of approximately the top 70 cm of the soil in the frost-layer.

Comparing Tables IV and V, we see that the apparent specific gravity and the water content both practically coincide with the measured values of the apparent specific gravity and saturated water content for the soil in its most densely packed state, as in Table VI. Thus the scattered ice-lenses represent water that has separated out of the other parts of the soil which have frozen in a state of concretion. Hence these other parts will have no excess of absorbed water. Usually, then, the thickness of the scattered lenses and the amount of shrinkage of the concreted parts will nearly cancel each other. If so, we may suppose that in these parts of the soil there will be no frost-heaving, and consequently no subsidence when the thaw occurs.

TABLE VI

Measured samples	Water content	Apparent specific gravity
Saturated water content. (Dense packing)	0.28	1.91
Saturated water content. (Densest packing)	0.28	1.94
Water content at run-out point.	0.36	-
Water content at plasticity limit	0.22	-

The water content in samples Nos.7, 9 and 11 is above saturation; at these points, then, frost-heaving should occur. For No.9 (a sample which is in good accord with the whole series of measurements) the amount of frost-heaving may be calculated as follows. According to our previous paper, * the amount of frost-heaving Δl is:

$$\Delta l = 1.1\rho_a l(R - xr_o)$$

where ρ_α is the specific gravity of the wind-dried soil, r_o is the saturated water content, R is the total water content of the frozen earth, xr_o is the mean water content in the concreted earth, and l is the thickness of the sample.

From Tables IV and VI, $R = 0.30$ and $r_o = 0.28$, while $l = 90$ mm. After inserting a recently measured value for ρ_a, namely 1.55, there remains only x in question. In a previous paper, * we found that a suitable value for x is 0.9. Accepting this value $x = 0.9$, we have

$$\Delta l = 1.1 \times 1.55 \times 90(0.30 - \underline{0.9 \times 0.28}) = 7 \text{ mm}$$

* Nakaya and Sugaya, Teion Kagaku, Vol. 2, p.7.

Thus for sample No.9, the frost-heaving ratio $\Delta l/l$ is about 8%, or looking at the matter from the other side, we may say that if this part of the permafrost stratum melted there would be a subsidence of 8% of the thickness of the layer thawing. The frost-layer below the active layer, like the earth in frost-heaves in general, possesses a certain frost-heaving ratio, a fact which indicates that the freezing of the permafrost stratum likewise has taken place by cooling from above.

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§6. SUMMARY

The present research had as its main object the precise measurement of the distribution of ground-temperatures within the frost-layer at the time of deepest penetration of the active layer, information of interest as foundation data for construction work on permafrost soil. For the purpose, we made up two mechanically strong thermocouples, of which a precision of 0.01°C could be expected, and proceeded, by inserting these devices into holes bored in the permafrost, to determine precisely the ground-temperature distribution at depths of up to 3 m below the frost surface. We thus established that the temperature in the upper part of the frost-layer at the end of the thaw period is close to zero Centigrade, being within the range 0.0° to -0.1°C. Below about 1 meter, it fell to -0.3 or -0.4°C, the rate of fall in this neighborhood having the low value of 0.1°C/m. Moreover, we found that if the thermometer was suspended in an iron pipe set in the ground and readings taken at levels deep in the permafrost layer, this method too affords a very good means of measuring the ground-temperatures, if we accept an error of 0.2~0.3°C.

For the coefficient of thermal diffusion of the active layer in the thawed state, we obtained the empirical value 0.005 CGS units.

We determined the soil characteristics, mode of congelation, maximum water-content, maximum saturated water-content, etc., for the earth in the frost-layer. From these data, we were able to infer that the permafrost in this area has originated by cooling from above, as in ordinary frost-heaving. We were also able to calculate the frost-heaving ratio for part of our samples, and found the value here applying to be 8%.

The present investigation was undertaken at the request of the former Manchurian Railway Company. The authors express their gratitude to Mr. Y. Takano, who made the research possible, and to Mr. I. Sakabe, who did much to facilitate our work; also to the people at the site for their courtesy, and to Mr. S. Nakayama, who took part in the job and assisted in the observations.

TABLE IV

	Sample No.	Depth	Weight of earth	Volume	Relative water content	Apparent specific gravity	Remarks
Thaw layer	1	20cm	246 g	172 cm	0.39	1.42	Relatively dry black humus.
	2	100	316	172	0.36	1.84	Water-saturated brownish-black clay.
	3	150	330	172	0.32	1.92	Water-saturated tan clay.
	4	200	360	-	0.34	-	Water-saturated tan clay.
Frost layer	5	215	195	-	0.27	-	Fine ice-lens inclusions, as at (a) in Fig. 7.
	6	225	277	134	0.28	2.07	Fine lenses and nodules, as at (b) in Fig. 7.
	7	240	225	136	0.32	1.66	Lens-shaped inclusions.
	8	255	289	147	0.26	1.98	Practically no ice.
	9	268	373	187	0.30	1.94	Fine lens inclusions, as at (c) in Fig. 7.
	10	283	397	206	0.28	1.92	Lenses and nodules.
	11	217	338	-	0.59	-	Patchy freezing, soil character different, as at (d) in Fig. 7.

TABLE V

Earth Particle Sizes Below 2 mm, in percent.

	Sample No.	Depth	2.0~0.25 mm	0.25~0.05 mm	0.05~0.01 mm	Below 0.01 mm
Thaw layer	1	20cm	2.7%	0.4%	50.3%	46.6%
	2	100	2.8	0.9	42.5	53.8
	3	150	3.1	0.8	48.3	47.8
	4	200	1.4	0.7	47.8	50.1
Frost layer	5	215	0.9	0.7	47.3	51.1
	6	225	1.9	0.5	45.5	52.1
	7	240	1.9	0.6	47.1	50.4
	8	255	1.5	0.2	38.7	59.6
	9	268	2.1	0.7	43.5	53.7
	10	283	2.3	0.6	32.8	64.3
	11	217	3.0	0.8	47.0	49.2

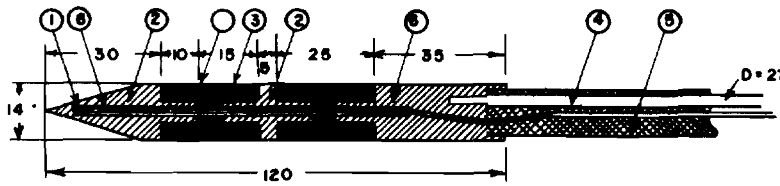


Fig.1. Protector tube and leads of heat-sensing part of thermocouple.

1. Heat-sensing part of device.
2. Brass.
3. Ebonite.
4. Piano-wire for insertion and withdrawal.
5. Protective insulation.
6. Oil hole.
7. Oil equalizer hole.

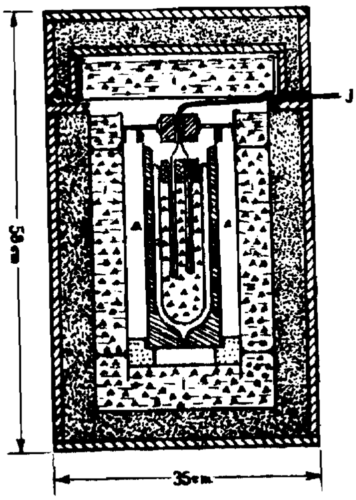


Fig.2. Apparatus for zero-point calibration.

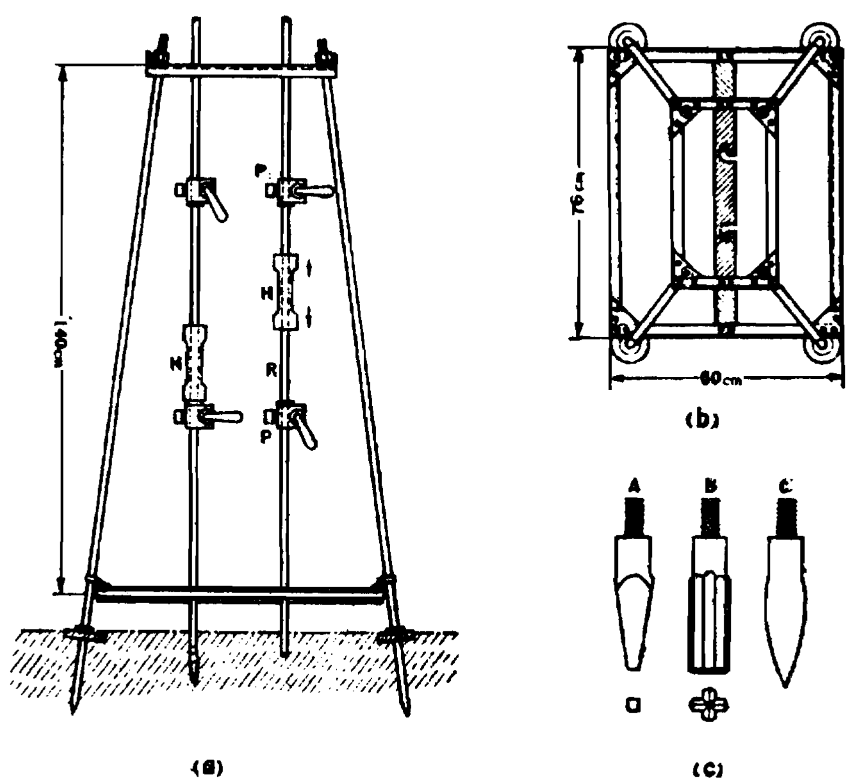


Fig.3.

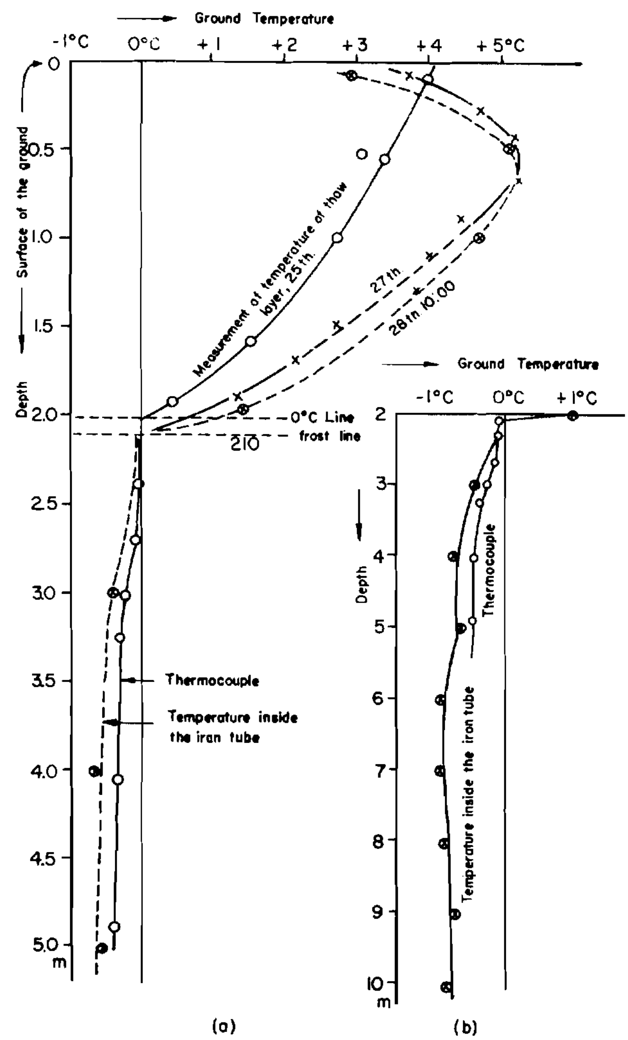


Figure 5

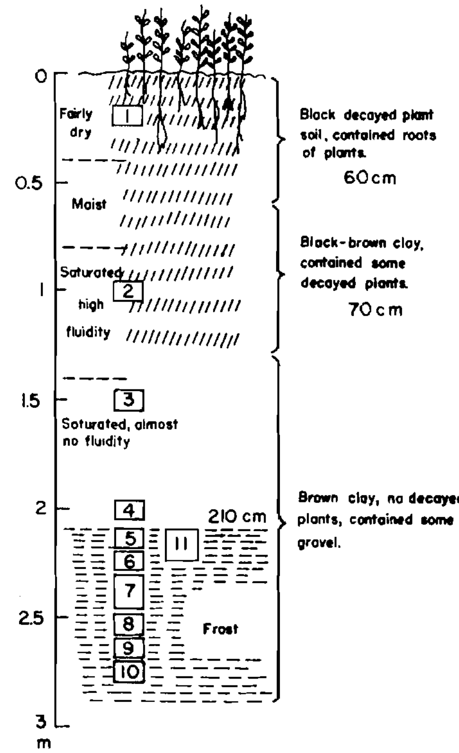


Figure 4

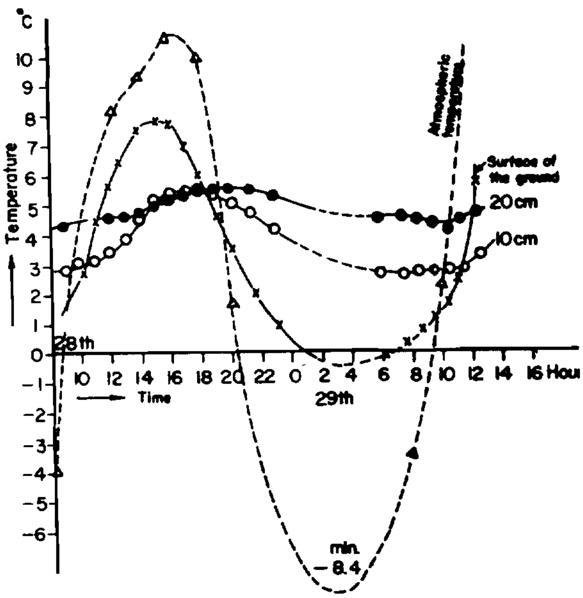
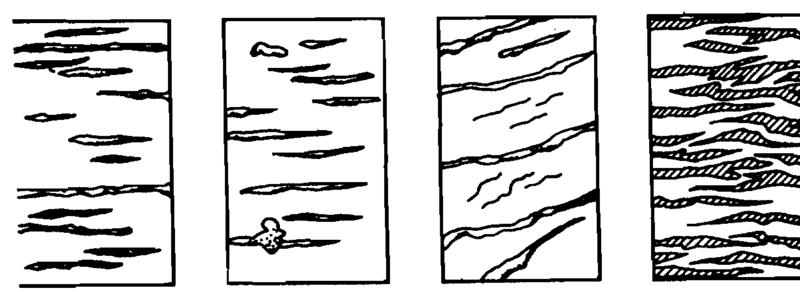


Figure 6



(a) No. 5 (b) No. 6 (c) No. 9 (d.) No. 11

Figure 7

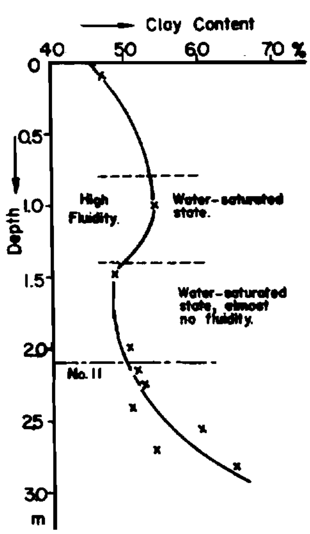


Figure 8