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Electrical Potentials Developed During Thawing of Frozen Ground

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RÉSUMÉ

Les auteurs ont mesuré les potentiels électriques produits lors du dégel du mollisol dans un site expérimental situé à Inuvik, dans les Territoires du Nord-Ouest. On a installé verticalement des sondes contenant des électrodes de cuivre disposées à intervalles réguliers dans un tertre argileux, dans un sol riche en glace à la jonction de trois tertres, ainsi que dans des tubes de carton enduits de cire, l'un rempli de gravier sableux et l'autre d'argile reconstitué, et plantés dans un tertre adjacent. La tension maximale mesurée de part et d'autre de la limite de la zone de dégel était de l'ordre de 500 mV dans le sol fin et d'environ 200 mV dans le sol grossier. La différence découle peut-être du plus fort degré d'humidité du sol fin.

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Electrical potentials developed during thawing of frozen ground

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ABSTRACT: Electrical potentials developed during thawing of the active layer in frozen ground have been measured at a test site in Inuvik, Northwest Territories. Probes containing copper electrodes spaced at regular intervals were installed vertically in a clay hummock, in an ice-rich soil at the junction of three hummocks, and in a sandy gravel and reconstituted clay in wax-coated cardboard tubes placed in an adjacent hummock. The maximum voltage measured across the thaw boundary was of the order of 500 mV in the fine-grained soil and about 200 mV in the coarse-grained soil. The difference may be due to the larger amounts of moisture in the fine-grained soil.

1 INTRODUCTION

Electrical freezing and thawing potentials have been measured during phase changes in aqueous systems such as pure water, dilute solutions of ionic solutes, and even moist soils and rocks. These potentials between the frozen and unfrozen parts of the system can arise from two different causes: from electrical currents and potentials specifically related to the phase change of water, and from potentials arising out of charge separation during freezing and ion incorporation, commonly known as the Workman-Reynolds effect. In soils, the observed potentials may well be a combination of both effects. In addition to polarization of water molecules and alignment of dipoles due to the potential barrier across the boundary between frozen and unfrozen zones, charges inherent on the surfaces of mineral particles can contribute to the development of potentials by exchange absorption processes in soils.

Freezing potentials have been reported in dilute aqueous solutions of various salts (see, for example, Drost-Hansen, 1967; Gross, 1968; Cobb and Gross, 1969) and in pure water during freezing (Gill and Alfrey, 1952; Gill, 1953; Murphy, 1970; Korkina, 1975; and Parameswaran, 1982). In addition, a reverse potential has been observed during melting of ice (Gill and Alfrey, 1952), although its magnitude was smaller than that observed during freezing.

Reports of observations of electrical freeze/thaw potentials in soils and rocks, however, are meagre and inconclusive. Whereas the freezing potentials observed in pure water and dilute solutions were of the order of a few volts, the magnitude of the potentials generated in freezing soils was usually of the order of a few millivolts only (Parameswaran and Mackay, 1983). Very few measurements of electrical freeze/thaw potentials under natural conditions have been reported. Aside from work by Borovitskii (1976), the only documented measurement of freezing potentials under natural conditions in the field is that of Parameswaran and Mackay (1983), who measured potentials developed on copper electrodes at various depths in the active layer at Inuvik, N.W.T. They also used this technique to study freezing potentials developed as permafrost aggraded at the bottom of an artificially drained lake on Richards Island in the Mackenzie Delta. Both Borovitskii (1976) and Parameswaran and Mackay (1983) have also observed potentials generated during thawing of frozen soil in the active layer.

As a continuation of field studies, probes were recently installed in different materials in the active layer at a site near Inuvik, N.W.T., to study the nature and magnitude of the electrical potentials generated during freezing and thawing of the ground under natural conditions. Preliminary results from the initial measurements are presented in this paper.

2 FIELD INSTRUMENTATION

Five pairs of electrode and thermocouple probes were installed in late August 1983 in an area of colluvium where earth hummocks are well developed (Figure 1). The electrode and thermocouple probes were made of PVC tubing, 20.6 mm OD, 12.7 mm ID, each 2.5 m long and closed at the bottom. Each probe consisted of 14 copper electrodes in the form of circular bands, 20.6 mm in diameter and 12.7 mm wide with a wall thickness of 1 mm, installed in grooves spaced 150 mm apart along the PVC tube. Coaxial cables were soldered to the electrodes and the wires were led through the centre of the tube and connected to the terminals of a rotary switch. Each thermocouple probe had 14 copper-constantan thermocouples installed 150 mm apart at positions corresponding to those of the electrodes.

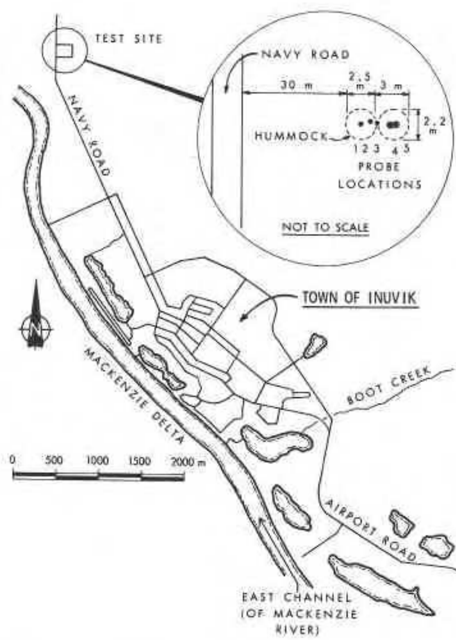


Fig. 1. Location of test site near Inuvik, N.W.T

The thermocouple wires (24 gauge, with an outer glass fibre sheath) were brought up through the centre of the PVC tube and connected to a rotary switch. A precision voltmeter with an ice bath reference junction was used to measure ground temperatures.

Pairs of probes were installed vertically side by side to a depth of about 1.5 m (the depth of the frost table) at five different locations (Figure 1). Probes 1, 2 and 3 were installed in augured holes about 25 mm in diameter, with the bottom electrodes below the late August frost table. Probe 1 was in the middle of a hummock about 2.5 m in diameter and probe 2 was between the centre and edge of the hummock. Probe 3 was in a depression at the junction of three hummocks; much ice was encountered when drilling here. Probes 4 and 5 were installed in open-end, wax-coated cardboard tubes, 300 mm in diameter, at the centre of an adjacent hummock. One tube was filled with the local clay and the other with a sandy gravel brought from a nearby borrow pit. The centre of the hummock was excavated by hand to the frost table and the wax-coated cardboard tubes were installed vertically and then backfilled.

An electrode probe and a thermocouple probe were placed side by side in the middle of each tube and the respective soils placed in the tubes and compacted by ramming with a rod. The materials were then saturated with water. As the tubes were open at the bottom, much of the water probably drained away. The fine-grained clay material would retain some moisture, but the gravel would lose most of it. Figures 2 and 3 indicate the locations of the probes and the positions of the electrodes in each probe; Figure 4 shows the site following installation.

3 DISCUSSION OF RESULTS

Although the probes were installed in late August 1983, no readings were taken during the freezing period of 1983-84. Regular bi-weekly readings were begun only in June 1984. The potential (DC voltage) at each electrode with respect to the bottom one (number 0) was measured using a precision voltmeter. Ground temperatures were also measured at the depths corresponding to each electrode.

Typical curves showing the variation of voltage and temperature with depth below the ground surface are plotted in

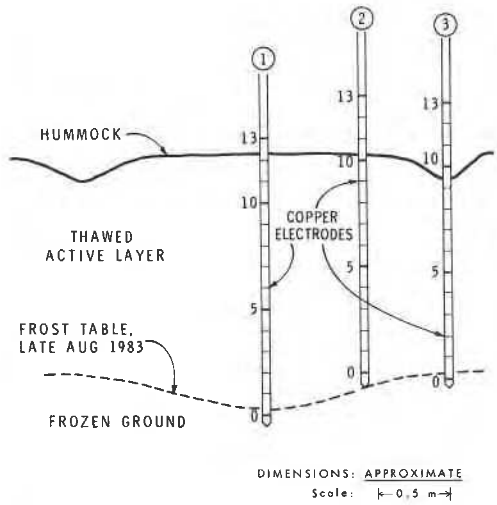


Fig. 2. Schematic diagram showing probe locations 1, 2 and 3 in a hummock

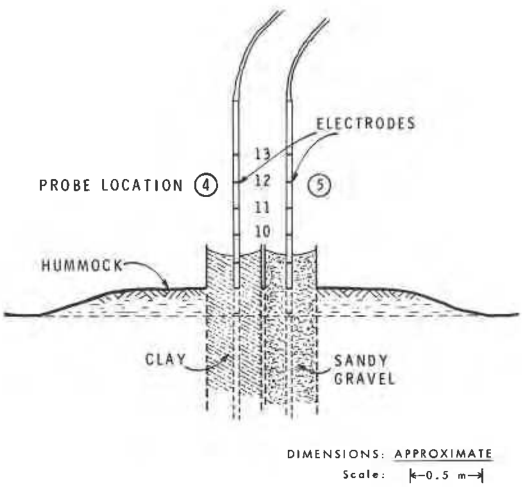


Fig. 3. Schematic diagram showing probe locations 3 and 4 in a hummock

Figure 5(a to e) for the five probe locations, covering the thaw season from June to September 1984. It may be seen that there is an abrupt change in the magnitude of the voltage at the thawing front (as measured by the electrodes on the probe). Since ions present on the mineral surfaces, soil moisture content,

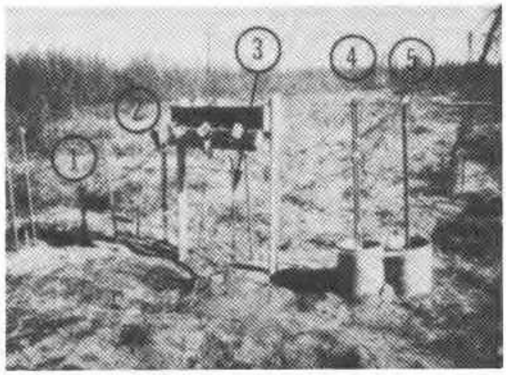
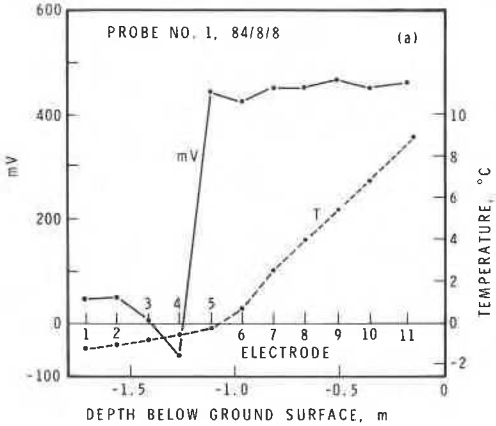
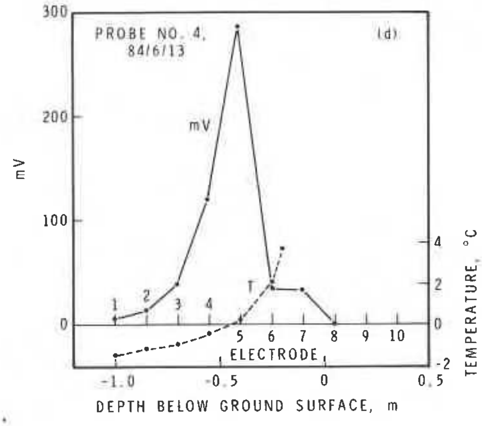


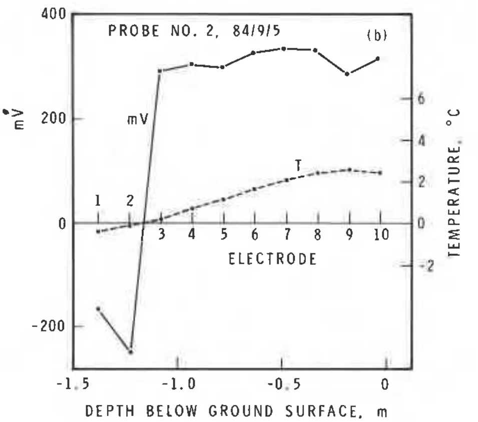
Fig. 4. Site after installation of probes

and concentration of ions in the soil water are unknown variables, it was impossible to predict the sign of the change in potential with confidence. Nevertheless, it is significant that there is a potential induced in the electrode located at the thawing front and that it is quite evident in each soil investigated.

The thawing potential may be taken as equal to the difference between the values of the voltages on electrodes in the frozen and unfrozen parts of the ground. For example, at probe 1 in the centre of the hummock the induced voltage measured on electrode No. 4 (located in frozen ground at a temperature of -0.5°C) was -62 mV, whereas that on electrode No. 5 (at a temperature of -0.2°C) was +445 mV (Figure 5(a)). Thus the potential across the thawing interface at this location can be considered to be 507 mV. (The temperature at which freezing/thawing of fine grained soils occurs is usually less than 0°C, so that the temperature indicated at electrode No. 5, where thawing was supposed to occur at the time of measurement, was -0.2°C. There may also be an error in the temperature observations owing to limitations in the accuracy of field measurements.) Figure 5(b) shows that at probe 2, in the same hummock, the potential measured between the frozen and thawed ground was 540 mV, this being the difference in the voltage induced on electrodes No. 2 and 3 at depths where temperatures were -0.2 and +0.2°C, respectively. The magnitude of these







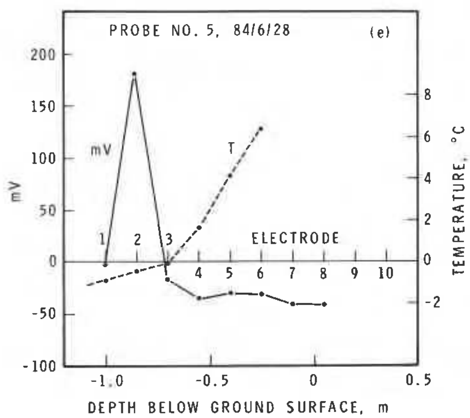
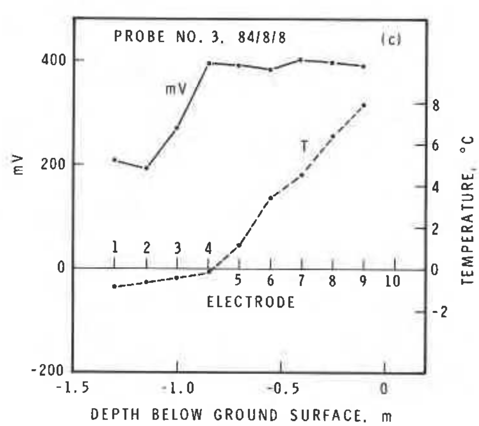


Fig. 5(a-e). Variation of voltage induced on the electrodes at different depths below the ground surface and corresponding temperature for locations 1 to 5, June-September 1984



potentials in clay is similar to the freezing potentials reported earlier by Parameswaran and Mackay (1983).

At probe 3, where much ice was encountered during drilling, the jump in potential across the boundary between the frozen and unfrozen zones was about 200 mV (Figure 5(c)). Figure 5(d) shows that the potential measured across the thaw front in the clay in the cardboard tube at probe 4 was about 280 mV. In the gravelly material in the tube at probe 5 the potential across the thaw boundary was 180 mV (Figure 5(e)).

Values of the maximum electrical potentials observed at the thawing boundary in materials at the five different locations are summarized as follows:

Probe	Material	Potential across Thawing Front (mV)
1	Natural clay at centre of a hummock	500
2	Natural clay in hummock	540
3	Ice-rich soil at junction of three hummocks	200
4	Clayey soil in waxed cardboard tube	280
5	Sandy gravel in waxed cardboard tube	180

Under natural conditions the fine-grained, clayey soil in the middle of the hummock developed a much larger potential between frozen and unfrozen zones than did the ice-rich soil at the junction of the hummocks. In the reconstituted condition also, the fine-grained, clayey material showed a higher potential than did the coarse-grained material. These differences can probably be attributed to the larger amounts of moisture present around soil particles in the fine-grained soil.

It is not clear whether the potentials measured between frozen and unfrozen zones during thawing of the ground are really thawing potentials, the reverse of the freezing potential reported by several authors. Although Borovitskii (1976) as well as Parameswaran and Mackay (1983) have reported potentials developed in the field during thawing of the active layer, the latter have speculated that such potentials may result when meltwater percolates downward to the still-frozen lower levels and freezes there, causing the reported freezing potential. This possibility was based on the observation that during the summer thaw period water may migrate from the thawed part of the active layer into the still-frozen lower layers of the ground to re-freeze and increase the ice content there (Cheng, 1982; Mackay, 1983; Parmuzina, 1978; Wright, 1981 and 1983). Gill and Alfrey (1952) observed that in pure water the thawing potential is of smaller magnitude than the freezing potential. Workman and Reynolds (1950) discounted any possibility of a thawing potential in dilute solutions because of prior neutralization of accumulated charges in the ice, which behaves like a semiconductor. In the present measurements, the magnitude of the observed potentials was the same as that of freezing potentials observed earlier (Parameswaran and Mackay, 1983) in the same type of clayey soil at a nearby location.

The dispute as to whether there is a true thawing potential, or whether the so-called thawing potential is due to meltwater percolating downward and freezing in the still-frozen lower regions can perhaps be settled by careful laboratory experimentation. Suitable probes might be installed in a frozen soil that is then allowed to thaw from the bottom upwards, so that meltwater cannot flow by gravity into the unfrozen zone.

As readings were not taken during the freezing period of 1983-84, the variation in electrical freezing potential that developed with time on each electrode could not be plotted, as was done earlier (Parameswaran and Mackay, 1983). The few readings obtained do indicate, however, the development of freezing potentials. Figure 6 shows the variation of the potential in the ice-rich soil at each electrode, probe 3, as measured with respect to the bottom electrode located in the frozen ground 17 October 1984. At the depth corresponding to electrode No. 9, where the temperature of the ground was about −0.3°C, there is an abrupt potential drop. Figure 7 shows the variation of electrical potential and temperature with time for electrode No. 6, probe 1, in clayey soil at the centre of a hummock. Between 5 and 17 October, when the ground temperature at this electrode dropped from +0.1°C to −0.05°C, the potential induced on the electrode jumped from about 100 to 555 mV, indicating the development of a freezing potential of 455 mV.

It is hoped that current readings taken at regular intervals will establish a trend in the development of electrical potentials at the freeze-thaw boundary at all five locations.

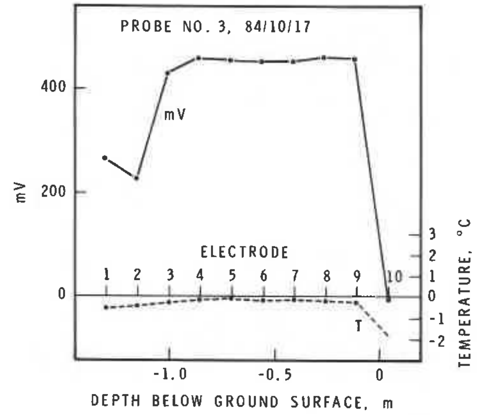


Fig. 6. Variation in voltage and temperature with depth for ice-rich soil at probe No. 3, October 1984

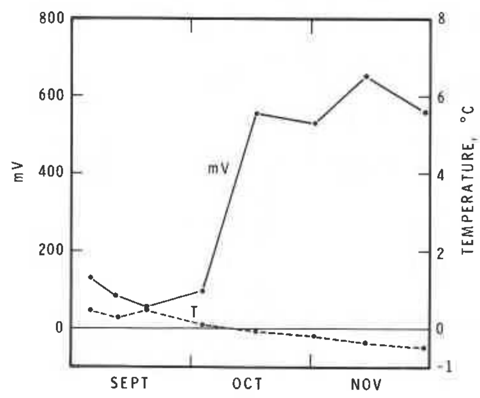


Fig. 7. Variation of electrical potential and temperature with time, electrode No. 6, probe No. 1, in a clayey soil

4 CONCLUSIONS

Electrical potentials measured during thawing of natural soils in the active layer and in reconstituted fine- and coarse-grained soils (by means of electrode and thermocouple probes at a field site in Inuvik) were of the order of 500 mV in a clayey soil in a hummock and 200 mV in a coarse-grained soil placed in a tube in the middle of another hummock. It is possible that with refinement in equipment and methods of measurement the technique can be used to detect the boundary between frozen and unfrozen zones in soils. From the magnitude of measured potentials in soils it may also be possible to determine their type and moisture content.

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