

Permafrost Depths, Lower Mackenzie Valley, Northwest Territories

J. ROSS MACKAY

ABSTRACT. Ground temperature records in the Lower Mackenzie Valley have been obtained for seven sites in the 1965 to 1966 period by installing thermistor cables in seismic shot holes drilled for the purpose. From the initial measurements, permafrost thickness is estimated at about 350 feet for Arctic Red River and 400 feet for a site 14 miles west of Fort McPherson. In the south-central part of the Mackenzie Delta, in an area of gradually shifting channels and infilling lakes, the depth is 350 feet, or possibly more. In the distal part of the Delta, where new islands are growing, permafrost is aggrading downwards in the saturated alluvial soils. At four sites within two feet of sea level, permafrost may be only 60 to 100 feet deep. Here, permafrost should continue to aggrade for many centuries more.

RÉSUMÉ. Profondeurs du pergélisol, basse vallée du Mackenzie, T.N.-O. Au moyen de cables à thermistor installés dans des puits sismiques forés à cette fin, on a relevé les températures dans le sol pour sept sites de la basse vallée du Mackenzie, pour la période de 1965 à 1966. A partir de ces premières mesures, on estime l'épaisseur du pergélisol à environ 350 pieds (120 m) pour Arctic Red River et à 400 pieds (135 m) pour un site localisé à 14 milles (23 km) à l'ouest de Fort McPherson. Dans la partie sud-centrale du delta, zone de chenaux mouvants et de lacs en voie de comblement, l'épaisseur est de 350 pieds (120 m), ou peut-être plus. Dans la partie distale du delta, où de nouvelles îles se forment, le pergélisol progresse en profondeur dans les matériaux alluviaux saturés d'eau. En quatre sites forés à deux pieds (60 cm) du niveau de la mer, le pergélisol peut n'avoir que de 60 à 100 pieds (20 à 34 m) d'épaisseur: il devrait continuer à y progresser encore pendant plusieurs siècles.

РЕЗЮМЕ. Глубина вечной мерзлоты в нижней долине реки Макензи, Северо-Западные Территории. При помощи установки кабеля с термисторами во взрывных сейсмических скважинах, пробуренных для этой цели в семи местах нижней долины р. Макензи, получены записи температуры грунта. Из начальных измерений толщина вечной мерзлоты определяется величиной около 350 футов для Арктической Красной реки и величиной в 400 футов в четырнадцати милях к западу от форта Макферсон. В южно-центральной части дельты р. Макензи, на территории постепенно меняющих свое местоположение рукавов дельты и заполняемых речными наносами озер, толщина вечной мерзлоты достигает 350, или даже больше, футов. В дальней части дельты, где образуются новые острова, мерзлота распространяется вниз в насыщенные аллювиальные грунты. В четырех местах, расположенных в двух футах от уровня моря, толщина вечной мерзлоты достигает только 60-100 футов. Здесь вечная мерзлота может продолжать расти еще в течение многих столетий.

Ground temperature records from permafrost areas in Canada are few and far between. In 1963, according to Brown (1966), there were only seventeen such locations in all of Canada and few have been added since then. Two of the seventeen stations are in the Lower Mackenzie Valley. Both sites are within 5 miles of Inuvik, N.W.T. and Brown reports permafrost over 300 feet thick. No other stations occur in the western Arctic. The purpose of this paper is to report on ground temperature measurements for seven new sites established in 1965 and 1966 in the Lower Mackenzie Valley (Fig. 1).

The ground-temperature measurements have been made with thermistor cables installed in shot holes drilled by seismic crews of Imperial Oil Limited and The British American Oil Company Limited. The shot holes, about 4 inches in diameter, were drilled rapidly (usually with air instead of water) so that temperature disturbances introduced by prolonged water

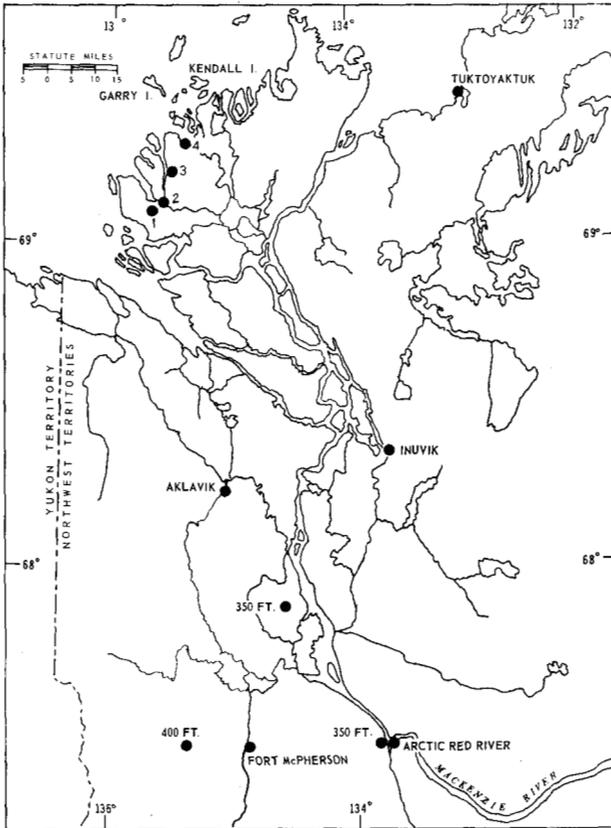


FIG. 1. Location map. Estimated permafrost depths are given in feet. Numbers 1, 2, 3, and 4 refer to the sites of temperature cables in the distal part of the Mackenzie Delta.

drilling has not occurred. After the cables were inserted some holes filled up with water. Therefore, temperature readings have usually been taken at intervals of months after drilling to permit a return to and a check on undisturbed conditions.

The temperature sensors used in the cables were thermistor beads (Yellow Springs Instrument Company series 400 beads) with a manufacturer's interchangeability tolerance at 0°C . of 0.2°C . The beads were protected from freezing damage either by brass jackets or one-inch diameter rubber-plastic pods. No malfunction due to freezing damage has been observed in the 80 thermistor beads installed. All of the thermistors were calibrated either by: the B.C. Research Council, Vancouver, B.C.; the Cold Regions Research and Engineering Laboratory, U.S. Army, Hanover, N.H.; or by the writer using a precision Leeds and Northrup Wheatstone bridge as described by Hansen (1966, p. 358) with an equivalent temperature error, in the operational range, of about 0.01°C . Readings in the field were taken both with the precision bridge and two small bridges, the latter calibrated to read within 0.03°C . of the precision bridge. In the southern Mackenzie site, however, only the two small bridges have

been used so far. As the cables have been frozen into the holes and so are non recoverable for later calibration purposes, clusters of three thermistors have been used at each measurement depth in four of the cables, thus permitting detection of any unusual drifting in a single bead. However, drift in beads calibrated over a five year period have been negligible.

ARCTIC RED RIVER SITE

The Arctic Red River site is two miles due west of the settlement of Arctic Red River at an altitude of 250 feet above sea level. A small shallow lake is located 600 feet to the south. The site, in the boreal forest, is covered with birch, 20 to 25 feet high, scattered spruce up to 10 feet high, and a thick growth of willow, alder, labrador tea, cranberry, and mosses. A 200 foot hole was drilled by Imperial Oil Limited in the Imperial Formation (upper Devonian sandstone and shale) and the cable installed in the early summer of 1965. On 12 August 1965 temperature readings were taken with a small bridge and on 23 June 1966 with the precision bridge. The two sets of readings differed by up to 0.4°C . in the top 100 feet but from 125 to 200 feet they agreed within 0.1°C . There are 12 probes in the cable, with a cluster of 3 probes at a depth of 30 feet. A downward projection of the 23 June 1966 profile (Fig. 2) suggests that permafrost bottoms at about 350 ± 15 feet.

FORT MCPHERSON SITE

The Fort McPherson site at $67^{\circ}26'N$, latitude, $135^{\circ}25'W$, longitude, is 14 miles due west of the settlement of Fort McPherson at an altitude of about 1,300 feet above sea level. The nearest water body is a lake one mile to the northeast. The hole was drilled, by Imperial Oil Limited, in an area of shale and sandstone (Lower Cretaceous age), to a depth of 100 feet by air, but had to be completed using water due to mudding problems. Temperatures taken 15 hours after installation of the cable ranged from 0°C to -0.5°C . Readings were taken on 10 August 1965 with a small bridge and on 4 August 1966 with the precision bridge. The two sets of readings agreed within 0.1°C . A projection of the 4 August 1966 temperature profile downwards suggests a permafrost depth of about 400 feet (Fig. 2). Although the Fort McPherson and Arctic Red River sites are at the same latitude, the Fort McPherson site is 1,000 feet higher; it has colder air temperatures; and the vegetation is tundra rather than forest.

SOUTHERN MACKENZIE DELTA SITE

This site is in the Mackenzie Delta at about $67^{\circ}51'N$, latitude, $134^{\circ}35'W$, longitude, at an altitude of about 35 feet above sea level. The site is on the floodplain of the Mackenzie River and is liable to inundation at break-up in May-June. Vegetation is spruce, with trees up to 50 feet or higher, willow, alder, and a ground cover of heaths and mosses. One 250-foot cable and six 50-foot cables were inserted along a seismic line in shot holes about

300 feet apart by The British American Oil Company Limited. In the 250-foot cable, clusters of three thermistor beads were placed at each of the following depths: 25, 50, 100, 150, 200, and 250 feet. In each of the six 50-foot cables, clusters of three beads were placed at 25 and 50 feet. Thus anomalous readings can be cross checked.

The 250 foot hole penetrated through 130 feet of frozen clay; from 130 to 150 feet, frozen clay with thin ice lenses; and from 150 to 200 feet, frozen sand. As only one set of readings with two small bridges was obtained (28 November 1966) the results must still be considered provisional, as the equilibrium temperatures may be lower than those recorded. Nevertheless, a plot of the temperature profile for the 250-foot hole suggests that permafrost may exceed a depth of 350 feet. When the temperatures at a depth of 50 feet for six of the seven cables are compared (one cable could not be located under the snow cover) they show a range of -2.4°C to -3.8°C , the highest temperatures being recorded closest to water bodies (cf. Johnston and Brown 1964; Brown *et al.* 1964). As the approximate depth of 350 feet is in the range expected by extrapolation from depths estimated at the Arctic Red River and Fort McPherson sites, near equilibrium conditions probably exist in the 250-foot hole. That is, the depth of permafrost in this area of slowly shifting channels and lakes, both infilling and thermokarst, appears close to steady state conditions in the 250-foot hole.

NORTH MACKENZIE DELTA SITE

In the spring of 1966, five 50-foot cables, each with a cluster of three thermistors at the end, were inserted into drill holes on the distal (seaward) end of the Mackenzie Delta (Fig. 1). The low alluvial islands of this area, beyond the limit of trees, are covered with sedges, horsetails, willows, and other plants tolerant of soggy conditions. All of the area is normally submerged in the early June break-up at which time a layer of sediment is deposited. In August-September, the islands may be flooded again whenever there is a strong westerly storm. One of the 50-foot cables was lost (i.e. covered with mud and the markers swept away by ice) during the 1966 break-up. Temperatures of the four remaining cables were taken on 22 June and 4 August 1966. In the intervening six weeks, temperature differences did not reach 0.1°C ., so the 4 August values are believed to be representative of the undisturbed temperatures. At a depth of 50 feet, the mean annual temperature changes little, consequently the temperatures of -0.4°C . for cable 1; -2.3°C . for cable 2; -0.7°C . for cable 3; and -2.3°C . for cable 4 may be taken as approximating the mean annual temperatures at the sites at a depth of 50 feet. Cable 1 was 100 feet inland from a channel which was about 2 feet deep at a distance of 50 feet offshore. Cable 2 was 65 feet inland and the channel was 2 feet deep about 150 feet offshore. Cable 3 was 30 feet inland and the channel was about 2 feet deep offshore. Cable 4 was 20 feet inland and the channel was about 2 feet deep 25 feet offshore.

The mean annual ground-surface temperature for a drill hole near Inuvik has been estimated at -4.6°C . (Brown 1966, p. 244). An extrapolation to the ground surface of the profiles from 200 to 100 feet of the Arctic Red River and Fort McPherson sites (Fig. 2) should approximate the mean ground surface temperatures of about $-4.5^{\circ} \pm 0.2^{\circ}\text{C}$. The mean annual ground surface temperature at Garry Island, for the 1963-66 period, at a hummocky tundra site is estimated at -6° to -8°C . In view of the fact that temperatures along the coast are lower than at Inuvik, a

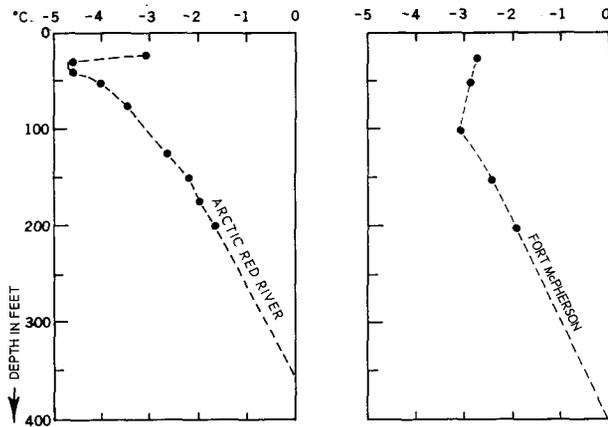


FIG. 2. Ground temperature profiles for the Arctic Red River site, 23 June, 1966, and the Fort McPherson site, 4 August 1966.

mean annual ground surface temperature of -5°C . seems conservative. If it is assumed that: (a) the mean annual ground surface temperature is -5°C .; (b) the temperature on 4 August 1966 at a depth of 50 feet is close to the mean annual temperature at that depth; (c) the mean annual ground temperature profile is linear, then permafrost at the four sites should lie within the depth range of 60 to 100 feet. Although the preceding assumptions can be relaxed, such as by assuming a mean annual ground-surface temperature of -6°C . and a steepening (non-linear) profile with depth, it is obvious that permafrost is thin, and only a third to a quarter the 'equilibrium' depth found farther south. This shows that permafrost is aggrading downwards. Barring a climatic change, a channel shift, or lake formation to provide a heat source, computations using Neumann's solution for formation of ice (Ingersoll, *et al.* 1954, pp. 190-4) modified for soils show that permafrost should continue to aggrade downwards for hundreds of years.

CONCLUSION

Permafrost at Arctic Red River is about 350 feet thick; near Fort McPherson about 400 feet. In the Mackenzie Delta the depth is highly variable because of the heat sources provided by lakes and channels. Even so, depths of at least 350 feet occur. In the distal part of the Mackenzie Delta, where shoals are being built up into islands, permafrost is aggrading downward, for the first time. The anomalously high temperatures at a

depth of 50 feet show that ground temperatures are far from equilibrium. At the sites of the four cables, permafrost is about 60 to 100 feet deep near the channels. Here, permafrost is undoubtedly aggrading downwards, and unless there is a heat source provided by a channel shift or lake formation, aggradation should continue for hundreds of years under present conditions of sedimentation, plant growth, and climate.

ACKNOWLEDGMENTS

The writer would like to express thanks to Imperial Oil Limited (L. R. Hatlelid, G. Rempel, J. G. Riley, G. A. Schlosser) and The British American Oil Company Limited (R. H. Carlyle, R. P. Prudholme) for their co-operation in installing the temperature cables. Funds for equipment came from the National Research Council, Northern Affairs and National Resources, and the University of British Columbia. Field transportation was supplied by the Geographical Branch, Ottawa. Mr. F. Carmichael and T. Gordon of Reindeer Air Services, Inuvik; R. M. Hill and J. D. Ostrick of the Inuvik Research Laboratory; and D. K. MacKay, Geographical Branch, helped with readings. Dr. G. Jacobsen arranged for calibration of some thermistors.

REFERENCES

- BROWN, R. J. E., 1966. Relation between mean annual air and ground temperatures in the permafrost region of Canada. Proceedings Permafrost International Conference Lafayette, Indiana, November 1963, *National Academy of Sciences - National Research Council, Washington Publication*, No. 1287, pp. 241-47.
- BROWN, W. G., G. H. JOHNSTON and R. J. E. BROWN, 1964. Comparison of observed and calculated ground temperatures with permafrost distribution under a northern lake. *Canadian Geotechnical Journal*, 1:147-54.
- HANSEN, B. L., 1966. Instruments for temperature measurements in permafrost. Proceedings Permafrost International Conference Lafayette, Indiana, November 1963, *National Academy of Sciences - National Research Council, Washington Publication*, No. 1287 pp. 356-58.
- INGERSOLL, L. R., O. J. ZOBEL and A. C. INGERSOLL., 1954. Heat conduction with engineering and geological applications. Madison, Wisc.: University of Wisconsin Press, 278 pp.
- JOHNSTON G. H. and R. J. E. BROWN, 1964. Some observations on permafrost distribution at a lake in the Mackenzie Delta, N.W.T., Canada. *Arctic*, 17:162-75.
- MACKAY, J. R., 1963. The Mackenzie Delta Area, N.W.T. Canada. Department of Mines and Technical Surveys, Geographical Branch, Memoir 8, pp. 88:94; 173.