PERMAFROST IN THE KNOB LAKE IRON MINING REGION

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This paper presents in outline the programme of exploration used in mapping permafrost in the Knob Lake (Schefferville, P.Q.) mine region, and the techniques used by the Iron Ore Company of Canada (IOCC) to overcome problems of mining in permafrost areas.

Permafrost in central Labrador-Ungava occurs as discontinuous bodies of various shapes and sizes within the upland terrain above approximately 2200 feet in elevation. In most mine areas of the Knob Lake district, frozen ground is absent. At two locations shown in Figure 1, Ferriman and Timmins, permafrost presents, however, a problem to mining. The active layer (seasonal freezing and thawing) varies from 5 to 10 feet in depth, and if there is no permafrost below that layer then the groundwater circulates freely in aquifers. Particularly under exposed windswept ridges, free of tree cover, permafrost or perennially frozen ground can extend to depths of 250 feet. These permafrost bodies are commonly elliptical in cross-section and are elongated parallel with rock strike and ridge crest trend. Ground temperatures vary from 25 to 32°F, and vertical isotherms at the freezing point parallel the slopes of ridges indicating sharp plunging boundaries to the permafrost (Figure 2). These boundaries often transgress rock types, and appear to be in close adjustment with surface climatic and vegetation conditions. Occasionally, pods of frozen ground are encountered at depths of 150 to 200 feet. These may be relics of colder climates during the Pleistocene.

EXPLORATION IN PERMAFROST

Exploration methods can be divided into three phases: short-term, intermediate and long-term. Aspects of each phase may occur concurrently in any given area. Short-term investigation of permafrost conditions over a period of one or two years takes place at the early stages of development of an area to be mined. Seismic and resistivity surveys used to determine depths to bedrock and water table respectively can also detect the upper permafrost table in many places. Seismic velocities and resistivity values often dramatically increase in permafrost. There is a 20-100 fold increase in resistivity of altered Iron Formation upon freezing (Bacon, 1957). Seismic velocities of frozen altered rock are frequently similar, however, to values in unaltered Iron Formation. Difficulties of interpretation obviously arise and other techniques are needed.

Test drilling may show signs of permafrost, but because mud is commonly used as circulating fluid, it is rarely possible to see ice in the recovered sample. Coring has not proved to be successful in Knob Lake ores. It is considered vital to any assessment of ice structure, water content, rock strength, etc., that good cores be obtained. Shallow test pits through the overburden frequently reveal permafrost if undertaken from August to late October. Back hoes are unable to cut into frozen ground without blasting. On many occasions, test pits have been terminated before the bedrock has been encountered.

Since geophysical methods and trenching only define the permafrost table, other techniques must be used to provide information about the geometry of permafrost. Temperature measurements in drill holes have been widely employed for this purpose at Knob Lake and elsewhere. Thermocouple cables containing 12 sensing junctions set at different depths have been installed, and the temperatures read at frequent intervals inside small shacks using a portable potentiometer, or a Speedomax recorder mounted on a sledge. At one mine area (Timmins 1), the cables were lowered into oil-filled holes cased with plastic tubing. At other sites, however, it has been just as economical to backfill the holes with sand, and although the cables were lost, the expense of casing was avoided. Furthermore, there was a risk of water penetration into the oil which may permit temperature migration in a vertical direction. Readings of ground temperature are used to construct isotherms along section lines. An example from the Ferriman area based on work completed in 1962 is shown in Figure 2. This section indicates the existence of cold "cores" beneath the ridge crest and an area of unfrozen ground (talik) in a poorly drained depression between two permafrost bodies. Temperatures obtained in the vicinity of Timmins 1 (Holes 2, 4, 6, 7 and 8) and Timmins garage site (Holes 9 and 10) are listed in Table 1.

Studies by Annersten (1964) in the Ferriman mine area in 1961-62 showed a correlation between the minimum depth of snow on ridge crest sites and the presence of permafrost. To further test this correlation and thereby determine whether snow depth is a useful tool in permafrost mapping, snow courses were established across areas where thermocouple cables were located. At Timmins 1, during the winter of 1967-68, snow stakes eight feet high were placed at 200 foot intervals along lines 500 or 1000 feet apart (Figure 3). These stakes were read at least once each month and after major snow and wind storms. Snow depth and density varies with relief, aspect and vegetation. Thick permafrost (200 feet) is probable in areas with less than a maximum of 16 inches of snow during the coldest months of January and February. Figure 4 depicts the seasonal snow cover for two courses located 1000 feet apart at Timmins 1 orebody. Very cold ground temperatures prevail at drill Hole 8 (see Table 1) whereas at Hole 7 in a sheltered vale the ore was not even frozen at a depth of 10 feet. Using the temperature and the snow data, a map of the proposed Timmins 1 mine area was constructed to show probable permafrost, marginal permafrost (31-32°F), unfrozen and unknown areas (Figure 3).

Vegetation reflects long-term climatic effects and in an area of discontinuous permafrost may act as an insulating agent and thus reinforce the effect of snow. Therefore, a map of vegetation which emphasizes the structural properties of the plants can assist in the understanding of permafrost distribution. A map of vegetation should also include coverage of local drainage conditions and frost heave features (e.g. polygons, stone stripes, etc.). In the Timmins 1 area, the distribution of tundra-like vegetation or rock desert closely agrees with areas of highly probable frozen ground (Figure 3). Stony earth circles are very characteristic of such surfaces. Poorly drained, boggy areas and surfaces covered by a dense growth of ground birch are more likely to be unfrozen in this region.

At the moment, therefore, short-term permafrost investigations at Knob Lake involve the analyses of seismic and resistivity geophysical data, examination of test pits, installation of thermocouple cables to depths of 50 to 300 feet, and snow and vegetation mapping. Without core drilling these data can only be used to prepare a preliminary estimate of permafrost conditions to be encountered in mining.

Intermediate range work involves the continued monitoring of thermocouple temperatures over a period of 2 to 5 years. This is mainly to examine changes in ground temperatures within the zone of annual fluctuation (30 to 50 feet). Work of this nature continues at Ferriman at thermocouple cable sites established by Annersten in 1961 (ibid). Analysis of such data eliminates seasonal effects in what could be a critical zone for shallow pits and for surface construction. Snow surveys have not been carried on for more than two years at any Knob Lake permafrost site. It may be advantageous to survey small areas over periods up to 5 years to eliminate seasonal differences.

There are two further programmes which have as yet not been attempted at Knob Lake, but which will receive some attention in the future. Both studies could be completed in 2 to 5 years. The first is a detailed appraisal of the structure of permafrost in any given rock type. This work by necessity has to be undertaken in an operating pit. Here the relationship between ice structure (in pores, lens or massive), water content, bulk density, strength properties, fracture pattern, lithology and mineralogy can be assessed. Preliminary studies in the Retty pit in March, 1968, showed considerable differences in ice structure in two rock units differing in lithology and joint pattern. The more massive and open jointed silica-carbonate iron formation contained ice lenses one inch or more thick, whereas the porous, altered ore was well bonded by minute crystals of ice in pore spaces. At any given depth there was no temperature difference between rock types, but differences in ice types and moisture content have an effect on ease of extraction (see below).

The second type of study which is envisaged in the future is a detailed analysis of the energy balance in areas that are perennially frozen. It is necessary to know more than just the ground temperature gradients in order to determine if any given occurrence of permafrost is in equilibrium with the present environment. The input of solar energy into the ground should be measured and this should be equated with loss of heat to the atmosphere. In practical terms this study required the installation of radiation equipment and temperature sensing devices above ground level. A study of this type is being planned for the Timmins 4 mine site.

Long-term objectives include the continued monitoring of thermal regimes at selected sites for an indefinite period. It is possible that subtle changes in climate will be reflected by changes in the temperature of the permafrost at depths of 50 feet or greater. More important from a mining point of view are attempts to modify the ground temperature regime by artificial means. Perhaps the most practical technique involves the construction of snow fences in an attempt to increase the insulating snow cover and thereby reduce the loss of heat from the ground during the winter. Efforts of this nature in the Ferriman area in the 1950's were unsuccessful as the programme had only short-term objectives. A tentative plan has been drawn up to construct snow fences of various experimental designs on an orebody which will probably not be disturbed for 10 or more years. Also important from a long-term point of view is the possibility of controlling ground and surface water systems near permafrost areas. Drainage diversion or dam construction may be other ways of modifying thermal regimes, and thus alleviating, in part at least, some of the problems of mining permafrost ores.

Many of these short, intermediate and long-term objectives are to be undertaken at the Timmins 4 orebody. In October 1968, nine thermocouple cables were installed and ground temperature measurements have commenced. A 150-point snow course in the form of a 200 foot grid has also been established. Geophysical surveys were undertaken in the summer of 1968 (Seguin, 1968), and research on the mechanics of stony earth circles has commenced at one site near Timmins 4. Figure 5 illustrates the extent of operations at Timmins 4 as of January 1969.

MINING PROBLEMS

There are three main problems in mining frozen iron ore in the Knob Lake region:

1. Blasting

Where the water content exceeds 10 per cent, ice crystals and lenses absorb a large proportion of the energy generated by each blast. This results in incomplete rupturing of the pit face which in turn sets in motion a vicious circle of events which are summarized in Figure 6 (Ives, 1962). Far more explosives are needed to reduce frozen ore to the required state than is the case with unfrozen ore. Cost of blasting is more than doubled as a denser drill hole pattern is employed, as well as more explosives (a slurry mixture and not simply AN.FO). Friction of the drill bit on frozen material causes the sides of the hole to melt and slump. The resultant reduction in hole depth and diameter causes uncertainties in correct location of explosives (Ives, 1962). More details on the problems and techniques of blasting in Knob Lake ores are contained in a recent paper by Lang (1966).

2. Removal of Ore from the Pit Face

Large blocks often originate from a frozen pit face. These are either pushed to one side to thaw out, or broken down by percussion. Congestion of the pit floor may result. Secondary blasting leads to an uneven pit surface hindering the movements of the shovel. In the screening plant the frozen blocks of about two feet diameter are difficult to break down, because of their hardness and elasticity. This results in inefficient reduction of ore to required sizes and increased cost of maintenance of equipment.

3. Transportation to Blast Furnace

Frozen ores are frequently above the critical 14 per cent water content and therefore need to be dried out in the drying plant at Sept Iles, P.Q. before loading into ships. Thawing en route to Sept Iles or in the ship results in "sticky" ores which are difficult to remove from the rail car or ship hold.

These problems have all been overcome to the point that frozen ores are mined. Blasting, thawing, crushing and drying problems, however, produce higher mining costs. Therefore, in the discontinuous permafrost zone, it is important to define the areas of frozen ore so that pit designs and mining schedules can be organized more efficiently.

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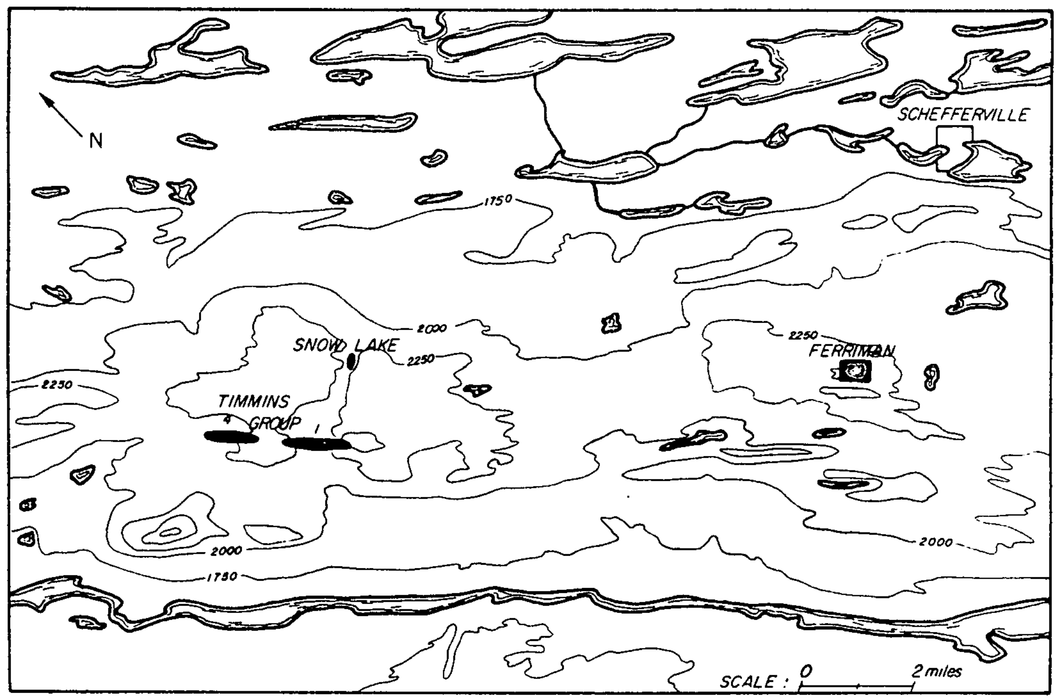

Fig. 1 Location of permafrost study areas. Ferriman and Timmins 1 and 4, in central Labrador-Ungava. The town of Schefferville provides the geographic reference point.

ISOTHERMS IN A SECTION ALONG THE FERRIMAN RIDGE.

ISOTHERM INTERVAL .2°C

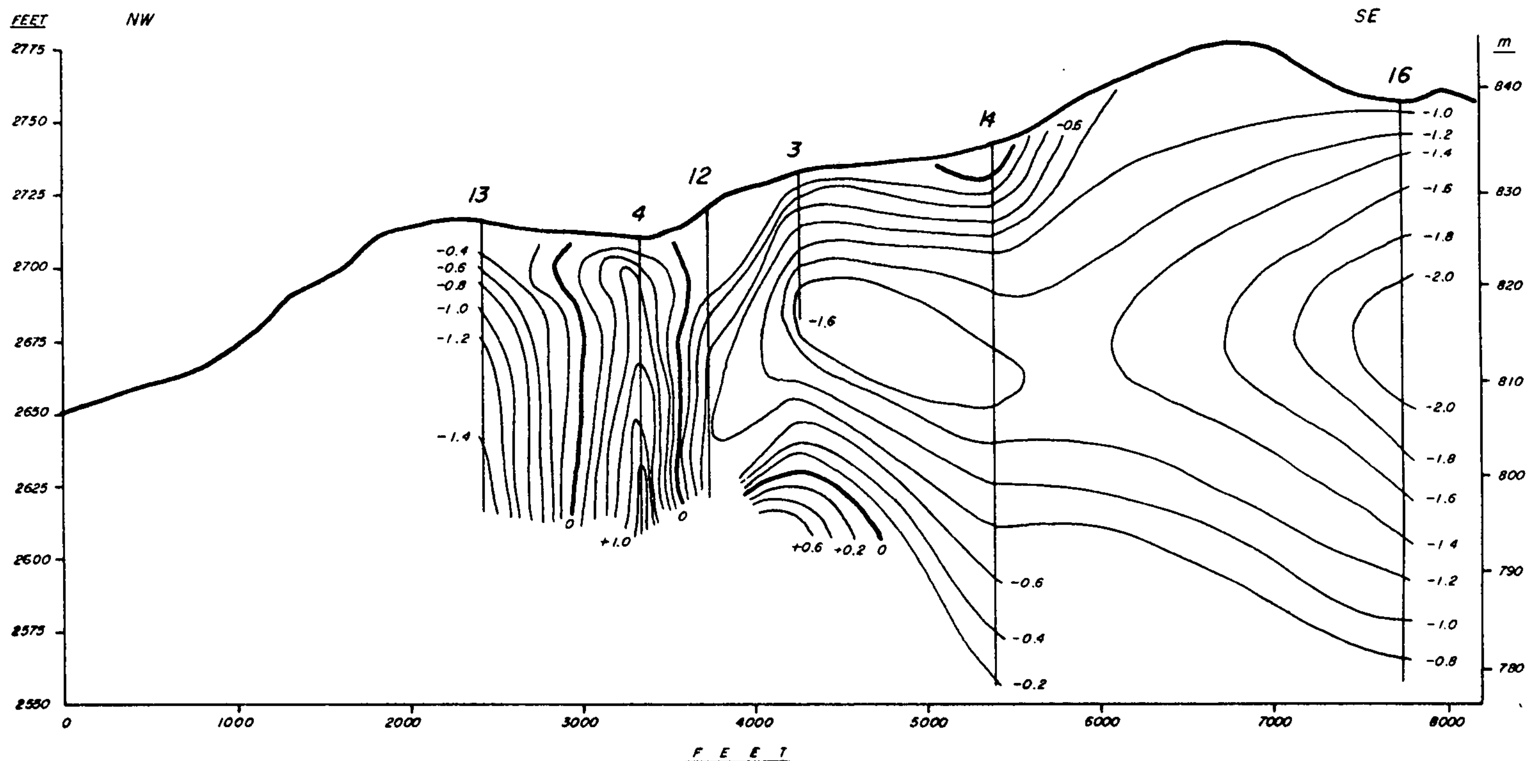

Fig. 2 Temperature distribution along a cross-section, which follows the crest of Ferriman ridge (Annersten, 1964).

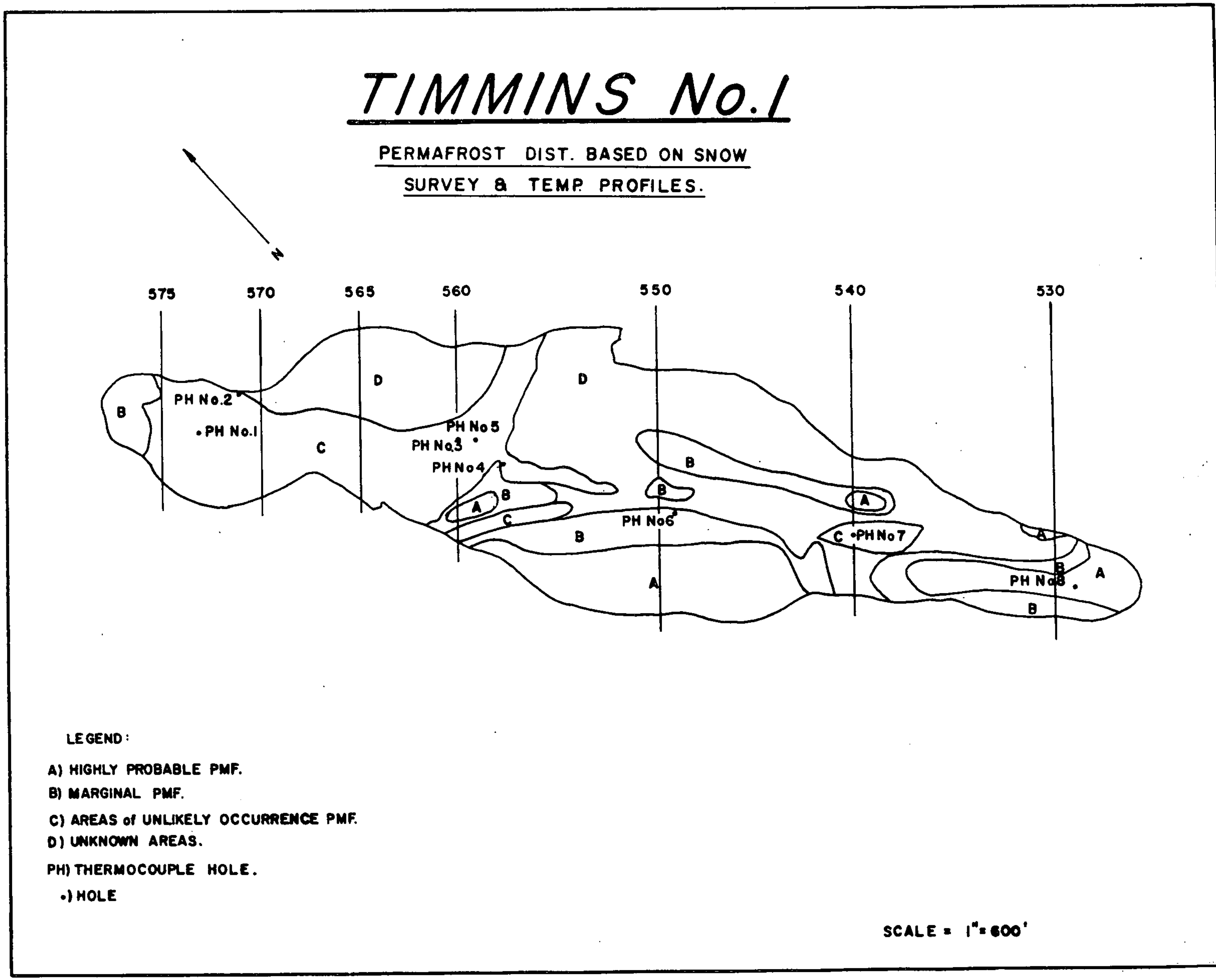

Fig. 3 Permafrost distribution at the Timmins 1 mine area. Holes containing thermocouple cables are shown on this map (e.g. PH No. 8).

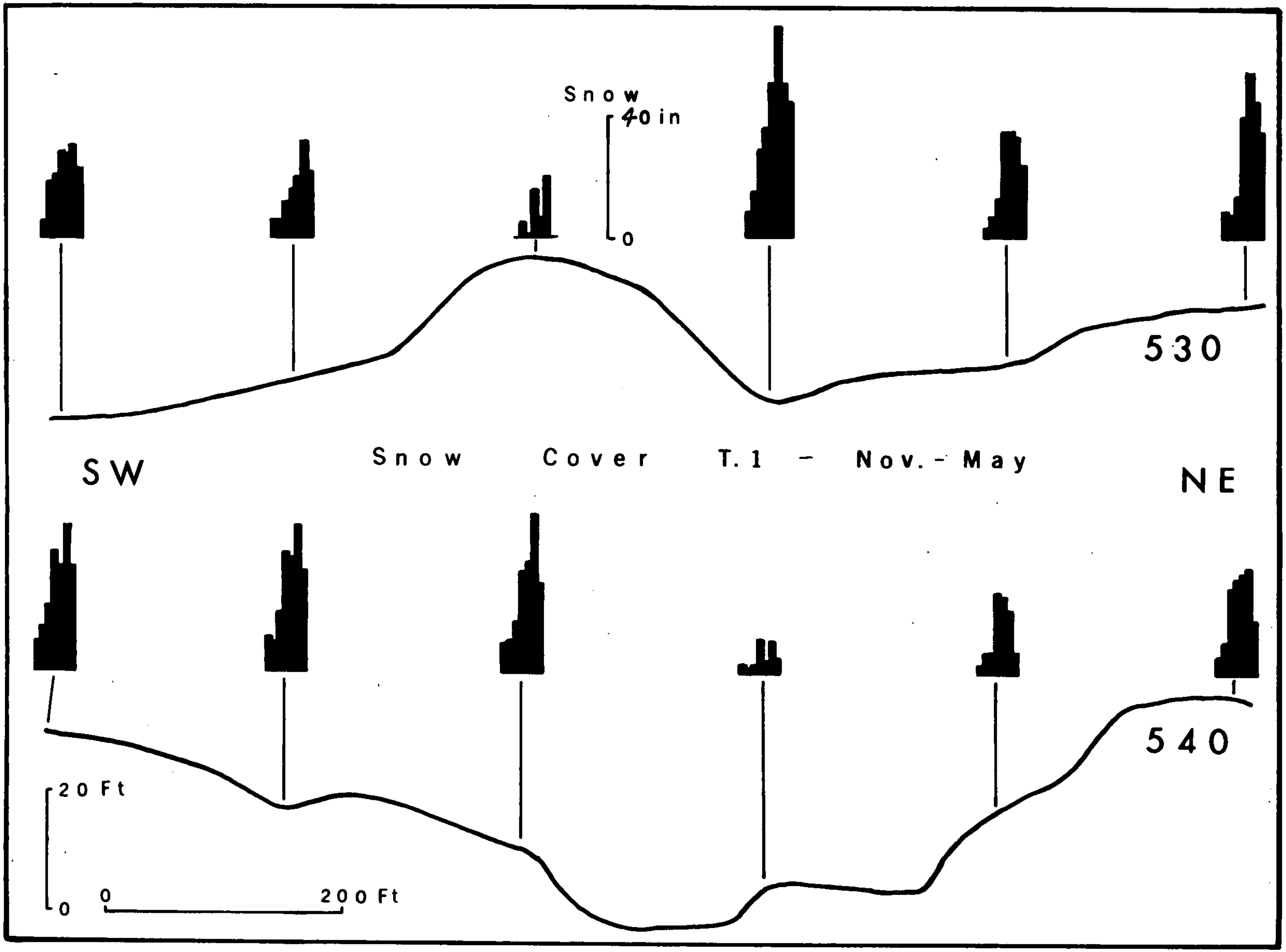

Fig. 4 Monthly snow depths for twelve locations on two snow courses at Timmins 1. The orientation of snow courses is approximately at right angles to mean wind direction (northwest). See Fig. 3 for location of snow courses.

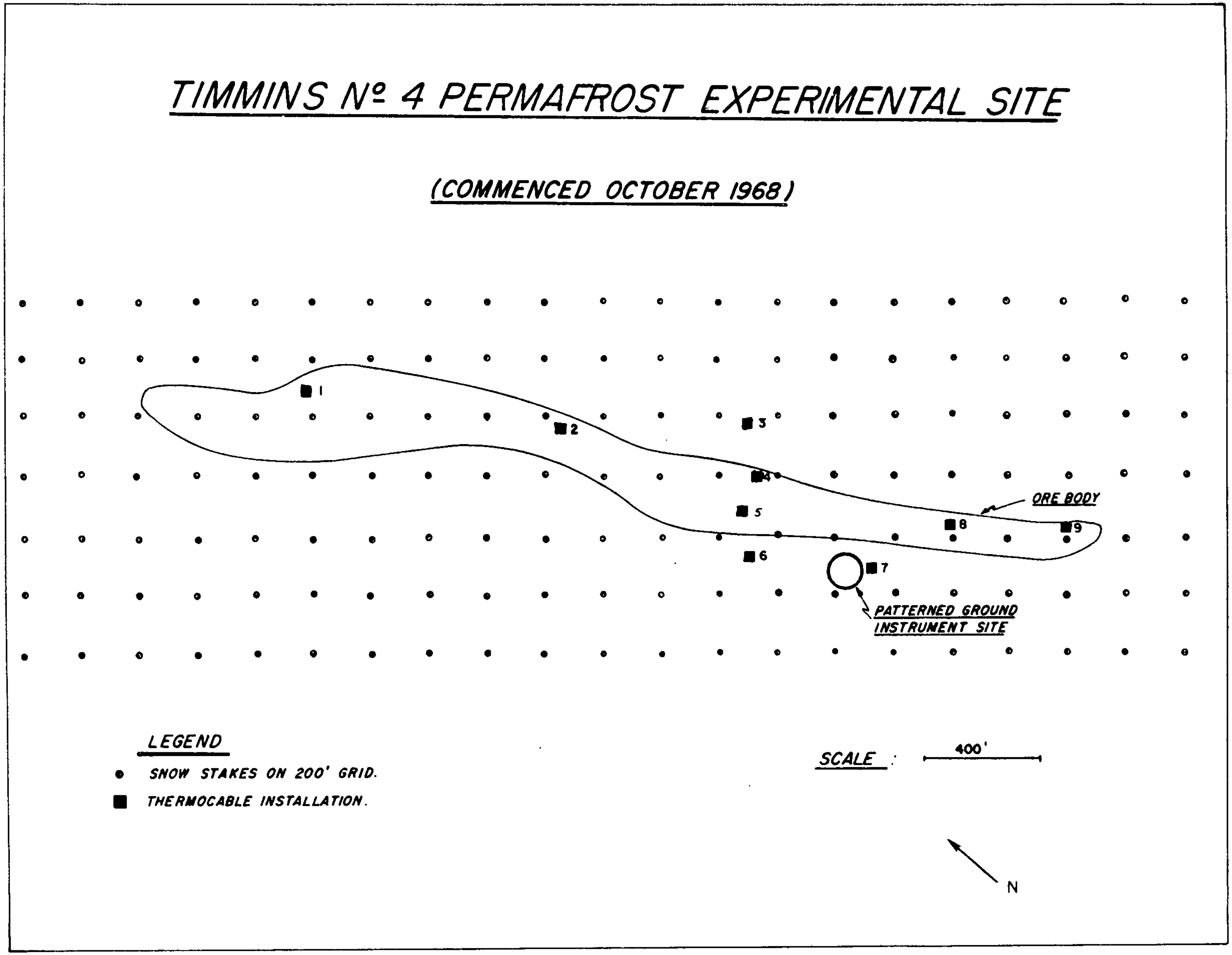

Fig. 5 Experimental site for permafrost research at Timmins 4 showing snow stake grid and thermocouple cable installations.

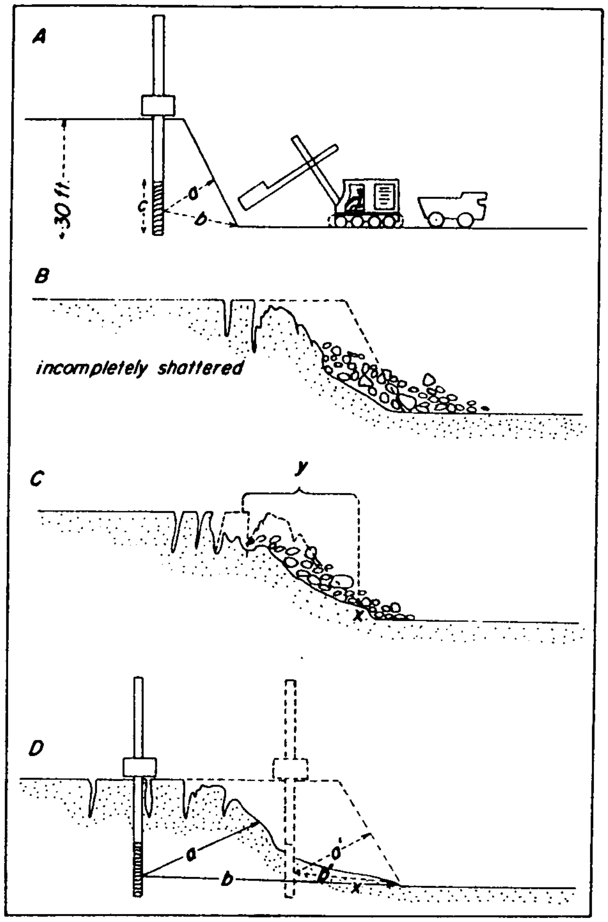

Fig. 6 Operational problems in mining frozen ore in an open pit (Ives, 1962).
(A) Idealized mining face; a and b are actual distances between the centre of the "charge", c, and the mining face; a, is termed the "burden", and b, the "toe distance".
(B) Effect of a blast on initial face with incomplete shattering shown by back breaks.
(C) Successive blast leaving an extended toe at x. The shattered ore in sector y is difficult to remove because the shovel is unable to approach ores at x. Not all the ore is broken down to a size which can be removed from the pit. Extensive back breaks are apparent.
(D) Actual mining face compared with idealized face showing the situation which would result in serious production delay. The extended toe, x, requires further drilling and blasting. Compare critical distances a and b with a' and b'.