C. I. Stevenson

CANADA

GEOGRAPHICAL PAPER No. 28

A Pilot Project for Permafrost Investigations in Central Labrador-Ungava

J. D. Ives

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PREFACE

This paper forms a contribution to the geographical investigations of sub-arctic Canada, a vast area which is rapidly growing in economic importance. More particularly, it should be of assistance to mining operations in the study area. But its principal intent is as a guide to future permafrost research in central Labrador-Ungava and in other related areas along the southern margin of the permafrost zone. It outlines the basic objectives of a research program and gives an account of the practical approach taken during the first year of investigations. The work was undertaken through the personal initiative of the author. It was supported by the Iron Ore Company of Canada, and drew advice and criticism from members of the Division of Building Research of the National Research Council. The assistance of these organizations is gratefully acknowledged.

N. L. Nicholson
Director
Geographical Branch

A PILOT PROJECT FOR PERMAFROST INVESTIGATIONS
CENTRAL LABRADOR-UNGAVA

INTRODUCTION

The purpose of this paper is to give an account of the practical difficulties encountered during initial permafrost investigations, June 1959 to June 1960, in the vicinity of Schefferville, central Labrador-Ungava. The installation of ground temperature and meteorological instruments is described and the program of work is discussed. Basically, it is understood that there is a correlation between scattered bodies of permafrost and climatic and terrain factors and, as the area under study is characterized by varied relief and vegetation, and hence, varied local climate, it lends itself particularly to such a detailed study.

Knowledge of permafrost conditions in central Labrador-Ungava has grown rapidly during the past 10 years, due largely to the exploration and mining activities of Iron Ore Company of Canada. However, actual excavation of ore and installation of temperature-measuring equipment in diamond-drill holes since 1957 has led to a radical re-appraisal of the earlier opinions on the extent and thickness of permafrost in an area which, according to the Glacial Map of Canada, (Wilson and others, 1958), lies well south of the "approximate southern limit of permafrost." Examination of surface conditions and local climate led to the realization that extensive permafrost occurrence should have been anticipated throughout the Schefferville sector of the ore-bearing deposits prior to the commencement of mining operations in 1954. While it is recognized that appraisal of permafrost conditions from an examination of the ground surface is a tentative procedure, it is believed that relatively extensive extrapolation of results from projects such as the one described here should give a useful estimate of the likelihood of permafrost occurrence. In view of the economic importance of obtaining such information within the zones of discontinuous and sporadic permafrost, especially when mining activity is rapidly expanding in these zones, a detailed report of the practical aspect of the investigations is presented. The results of the first year of observations and a discussion of their significance will be prepared as a separate report.

PREVIOUS WORK IN CENTRAL LABRADOR-UNGAVA

For the past thirty years a number of maps of permafrost distribution in Canada have been published, initially under Russian authorship (see Brown, 1960), and more recently by North American authors.

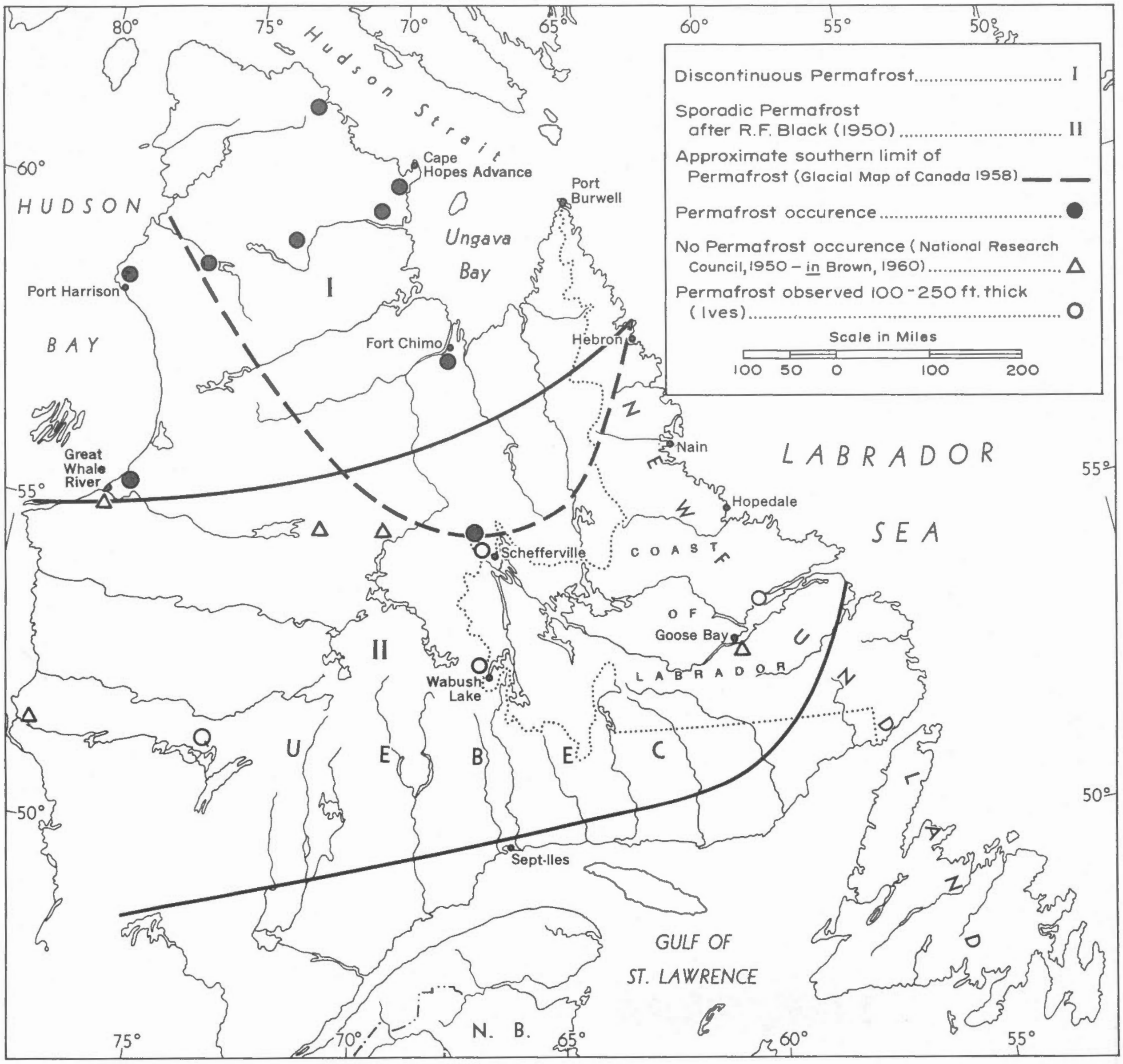

Figure 1 Permafrost data for Labrador-Ungava.

The map produced by Jenness (1949), was the first realistic Canadian attempt to map permafrost distribution and this was used in the preparation of the Glacial Map of Canada. It gives the southern boundary of continuous permafrost only and it is to be regretted that the legend on this map does not state that it is continuous, but simply reads - "approximate southern boundary of permafrost." The result is that it gives an erroneous impression of permafrost distribution, particularly in Labrador-Ungava. The map produced by Black (1950) is the most reasoned estimate of conditions to that date and demarcates zones of sporadic, discontinuous and continuous permafrost (Figure 1). Black's projected conditions for Labrador-Ungava have been effectively substantiated within the area studied by the present writer. The latest contribution by Brown (1960), adds considerably to the existing published ground data, although Black's "sporadic" category has been omitted because it was felt that the difference between "discontinuous" and "sporadic" permafrost is only one of degree and is not easily definable.

Actual field observations in central Labrador-Ungava have been few. Jenness (1949) reported permafrost at an elevation of 2,500 feet near Kivivic Lake, some 30 miles north-northwest of Schefferville, and Brown (1960) obtained important scattered observations of non-occurrence along the 55th parallel. None of these spot observations provide information on the actual thickness of the permafrost.

The occurrence of string bogs in an extensive area south of 55° N. in Labrador-Ungava, and of numerous palsa bogs north of 55° N. have been reported (Hamelin, 1959; Williams, 1959a). Although direct correlation with the presence or absence of perennially frozen ground cannot be made, these reports should prompt further investigations. Similarly, trenching operations during the demarcation of ore bodies by personnel of Iron Ore Company of Canada between 1949 and 1954 revealed the presence of "ground frost" at depths of 6 to 12 feet below the surface. Many of these observations were made in late August and September in broad, upland, windswept areas well above the tree line where wide areas of partially active and relic patterned ground forms occurred, and should have led at least to the suspicion of permafrost occurrences. Even in 1954 when excavation of ore at the Gagnon mine in the Schefferville vicinity revealed the presence of patches of relic permafrost well below the surface, this did not lead to the anticipation of the existence of permafrost underlying relatively extensive areas at greater elevations in the same vicinity. Henderson (1959, p. 81) aptly records the census of opinion prevalent at that time: "the whole.....area apparently is to the south of the belt of continuous permafrost. Small patches of modern permafrost may be present in a few restricted localities..... Some fossil masses ... have been penetrated by drilling. They record the time when the post-glacial climate was colder than that of the present day." In contrast, it is not too premature to estimate that one half of the ore reserves between Schefferville and Helluva Lake, a distance of 50 miles, are permanently frozen to a considerable depth (Ives, 1960).

The first logical approach to the problem was made by Bonnlander (1957 unpub., and 1958) as a seasonal employee of Iron Ore Company of Canada. During the 1957 summer Bonnlander installed 24 strings of thermocouples with 10- and 25-ft. thermocouple spacing in diamond-drill holes across the Ferriman orebody where mining in the autumn of 1956 had revealed extensive frozen ground. These investigations led to the first serious statement that permafrost may be extensive and not relic (i.e., residual from a former climate differing from that of today), but compatible with contemporary climatic conditions. Relic patches of permafrost, however, are probably widespread throughout south-central Labrador-Ungava. Bonnlander's unpublished report has been invaluable to the planning of the project described here. However, his thermocouple spacing and location, due to the pattern of the exploratory drilling, left much to be desired. In particular, a closer spacing in the upper layers was necessary before the presence or absence of talik* could be detected. This was essential before a firm conclusion could be drawn on the contemporary permafrost regime.

SCIENTIFIC OBJECTIVES

A fuller understanding of permafrost characteristics and development than presently available can possibly be obtained by detailed studies in marginal areas. Along the southern fringe of the great northern permafrost zone, where frozen ground is patchy in distribution and is wedging out, an opportunity is presented to gauge the relative effectiveness of the various factors influencing permafrost development. It is generally understood, of course, that low mean annual air temperatures result in greater heat loss from the ground in winter than heat gain in summer, thus resulting in negative ground temperatures, once thermal conditions have become stabilized. It is largely on the basis of air temperature data that permafrost distribution maps for large areas are computed, although it should be stressed that a mean annual air temperature appreciably below 32°F. would be required for the active growth of permafrost. It is also becoming apparent that small differences (of a few degrees) between the mean ground and the mean air temperatures are probably extremely significant to permafrost distribution. It is also generally accepted that heat transfer is influenced by the nature of the material involved and by the surface conditions. As specific examples, soil type, water content, vegetation type and snow depth may be cited. In the far north mean annual air temperatures are so low that this factor alone overwhelms the influence of what might be termed the secondary factors such as snow depth and vegetation. In the marginal southern zone, however, the secondary factors become of great importance. Thus, in the central Labrador-Ungava sector of the "marginal zone" the complexities of permafrost distribution can be more readily related to the secondary factors.

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*In this case, the unfrozen layer between seasonally and permanently frozen ground.

The over-all objective, therefore, was to attempt an evaluation of the relative importance of the secondary factors. It was intended that this in turn should provide the means for more accurate demarcation of probable permafrost occurrence from knowledge of the secondary factors alone. While detailed ground temperature observations would still be required in areas of economic exploitation, one of the basic objectives would be fulfilled if a preliminary map could be drawn up for a large area. When supplemented with the existing precise field data this should yield a more accurate map than is currently available.

The pilot project was intended to fulfill two objectives, therefore: (1) to provide provisional, qualitative data in a short time so that areas of potential permafrost could be mapped, at first in some detail in that sector of the Labrador Trough containing the highest concentration of iron ore, and secondly, more generally for Labrador-Ungava as a whole; and (2) to provide a fund of experience and preliminary data upon which a more precise and controlled study of the permafrost regime could be based.

The initial field plan was to map permafrost conditions in a limited area of varied relief and surface type by a precise study of ground temperature conditions, and by the examination of free-faces exposed during mining operations. Coincident with this the relief, vegetation and general surface type of the same area was to be mapped and detailed studies made of the mode of snow accumulation and eventual maximum snow depths. In addition, meteorological parameters were to be measured at three representative sites. The next phase of the study would be an attempt to relate the secondary factors to the ground temperature data and to evaluate the relative importance of the former. The final phase would then be to map surface conditions, relief and snow accumulation and from this predict potential permafrost distribution over wide areas where no ground temperature observations were available.

While full evaluation of the accumulated data has not yet been completed, sufficient study has been made to allow the suggestion that mapping permafrost in the manner outlined above will be practicable.

TOPOGRAPHICAL CONDITIONS

The general area

The main upland section of the iron-bearing Proterozoic sedimentary rocks lies along the western margin of the Labrador Trough between Schefferville and Helluva Lake. It is bounded on the west by the deep structural Howells-Goodwood valley system which separates it from the rolling gneissic hills of the Archaean province further west, while eastwards the land falls away abruptly into the broad "Knob Lake vale." Briefly, the area is characterized by a series of sub-parallel ridges and valleys, structurally controlled and aligned

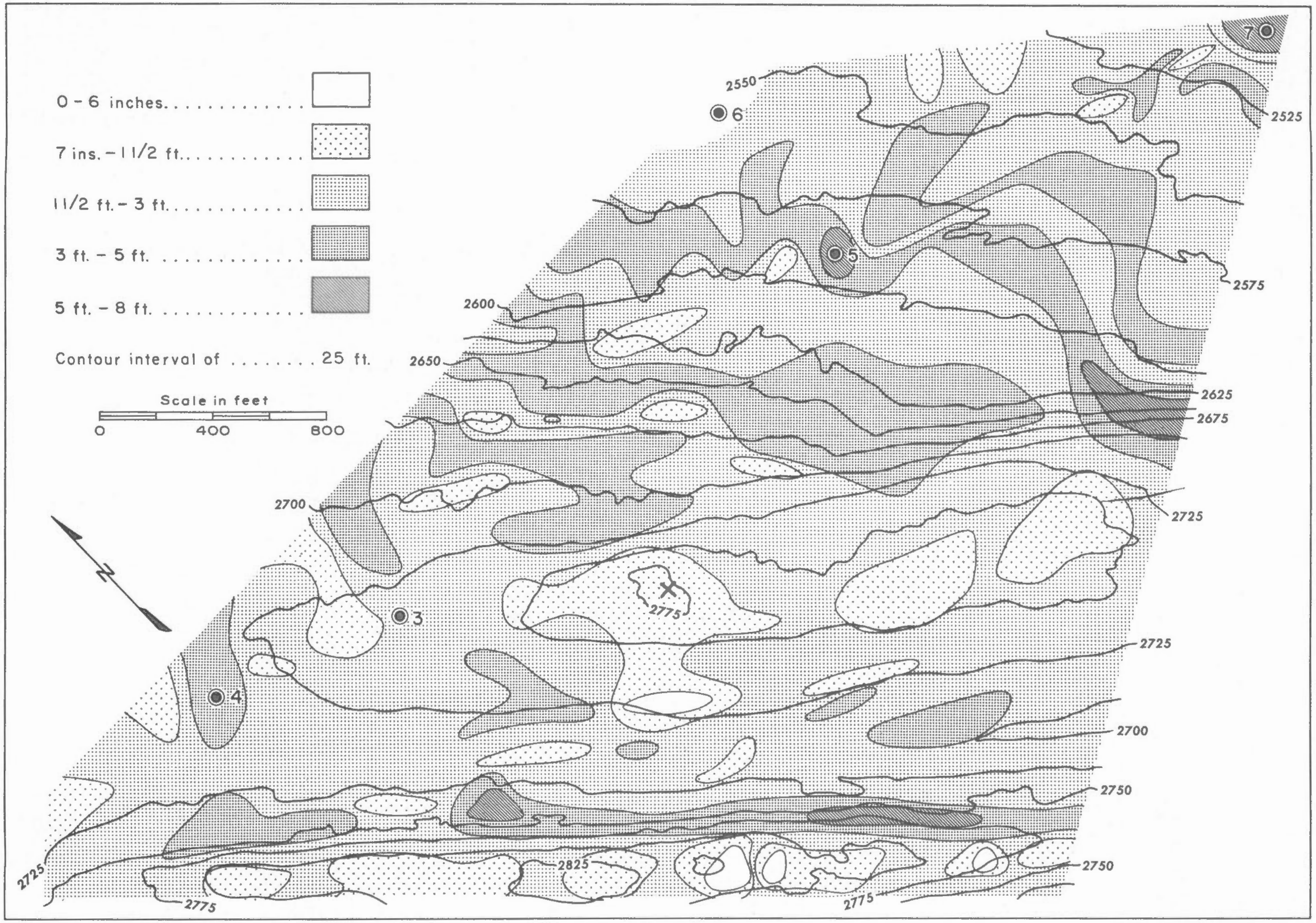

Figure 2 Sample map of snow depth distribution for late winter, 1959/60. (Data collected and plotted by M. Camille Roy).

north-northwestwards and is crossed and re-crossed by the Quebec-Newfoundland boundary. Local relief is of the order of 600 feet, while maximum relief is about 1,200 feet.

Summit elevations rise from 2,500 feet above sea level in the Schefferville vicinity to 2,900 feet in the northern section west of Helluva Lake. The strong structural control, including the topographical expression of a complex of thrust faulting and small-scale cross faulting, has produced steep slopes in many areas. This is particularly characteristic of the southern half of the area, although the northern section also includes broad areas of undulating upland country. This high ridge and valley tract varies in width from 2 to 8 miles and contains a high proportion of the proven ore reserves of Iron Ore Company of Canada.

The complexity of relief has naturally led to a complexity of vegetation distribution, ranging from barren, windswept ridge crests with a true tundra and arctic rock desert environment, to relatively luxuriant stands of closed-crown sub-arctic spruce woodland in the more sheltered valleys. This variety of relief and vegetation cover, and its effects upon snow drift, and hence heat loss from the ground in winter, is reflected in the complex pattern of permafrost distribution. While it renders difficult the extrapolation of ground temperature data to areas where no ground temperatures have been measured, the contrast in conditions over small areas is ideal for an attempt to evaluate the effect of varying surface cover, relief and local climate, on the ground temperature regime.

The study area

An area approximately 4,000 by 2,000 yards in extent lying 5 miles west of Schefferville in the Ferriman mine vicinity, was selected for detailed study (Figure 3). It embraces the bulk of the Ferriman orebody number 1 and ranges in altitude from 2,000 feet in the southeast to 2,550 in the west. The contours on the map are related to Iron Ore Company of Canada assumed datum of 1,914 feet for the surface of Knob Lake. In the text, altitudes have been corrected to 1,645 feet, based upon Topographical Survey data for 1955. The area was selected to include the fullest range of relief and surface type possible (Figures 9 and 10). Approximately two-thirds of the area lies in the lichen heath-rock desert zone; the remainder can be divided roughly between the sub-arctic woodland, and woodland-heath transition zones (Figure 4).

THERMOCOUPLE INSTALLATION

Of the twenty-four strings of thermocouples utilized by Bonnlander in 1957, only three had survived mining operations, and these were of limited value because the vertical spacing of the individual thermocouples was 20 feet. Their locations were originally determined by the geological exploration drilling program, test drill holes being used for installation purposes. Although readings on these strings provided an invaluable reconnaissance knowledge of ground temperature conditions across the orebodies, it was apparent that exploration drill sites did not necessarily lend themselves to detailed permafrost research. For the present study it was possible to select the drill sites specifically for thermocouple installation. As a result of this, four pairs of thermocouple strings were sited so that, for each pair, some of the variables at the surface which affect ground temperature conditions could be eliminated. In this way the relative significance of the individual variables, such as relief, vegetation, snow depth, could be best evaluated. With one exception, the first eight strings were installed between June and September 1959. In December of the same year, a further three strings were inserted in an attempt to evaluate the effect of actual mining operations on ground temperature regime. Although these strings were intended for a rather specialized study, they provided extremely valuable data for the project as a whole. The thermocouple strings are numbered from 1 to 11 and a brief description of the site of each is given below; their locations are shown on Figures 3 and 4.

Site 1. Installation was effected on 20th June, to a depth of 60 feet,* at a point 200 feet beyond the limit of the northeastern hit. The site was on level ground from which the surface material had been stripped during the previous summer. It was at an elevation of 2,360 feet above sea level in an area of lichen-heath vegetation and of moderate winter snow accumulation.

Site 2. Installation was completed on 29th June to a depth of 185 feet and at an altitude of 2,205 feet. This string was located within the woodland-heath transition zone with a steep slope to windward so that winter snow accumulation was expected to be heavy.

Site 3. A depth of 49 feet only was obtained for this set on account of difficulties of drilling in very hard blue ore. Installation was completed on 30th June at an elevation of 2,468 feet. The site formed an open convex slope on one of the highest ridge crests giving maximum exposure conditions to the prevailing northwest winds (Figure 14). The surface was characterized by a broken lichen mat with numerous active stony earth circles, implying little or no snow cover for much of the winter (Williams 1959b).

Site 4. Installation was completed on 7th July, to a depth of 96 feet, at an altitude of 2,443 feet, only 25 feet lower than site 3 and 300 yards to the north of it. This string was sited in a broad, shallow

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*Individual thermocouples in each string were spaced at 2-foot intervals below the surface for the first 20 feet, then at 5-foot intervals to 40 feet, and at 10- and 20-foot intervals at greater depths.

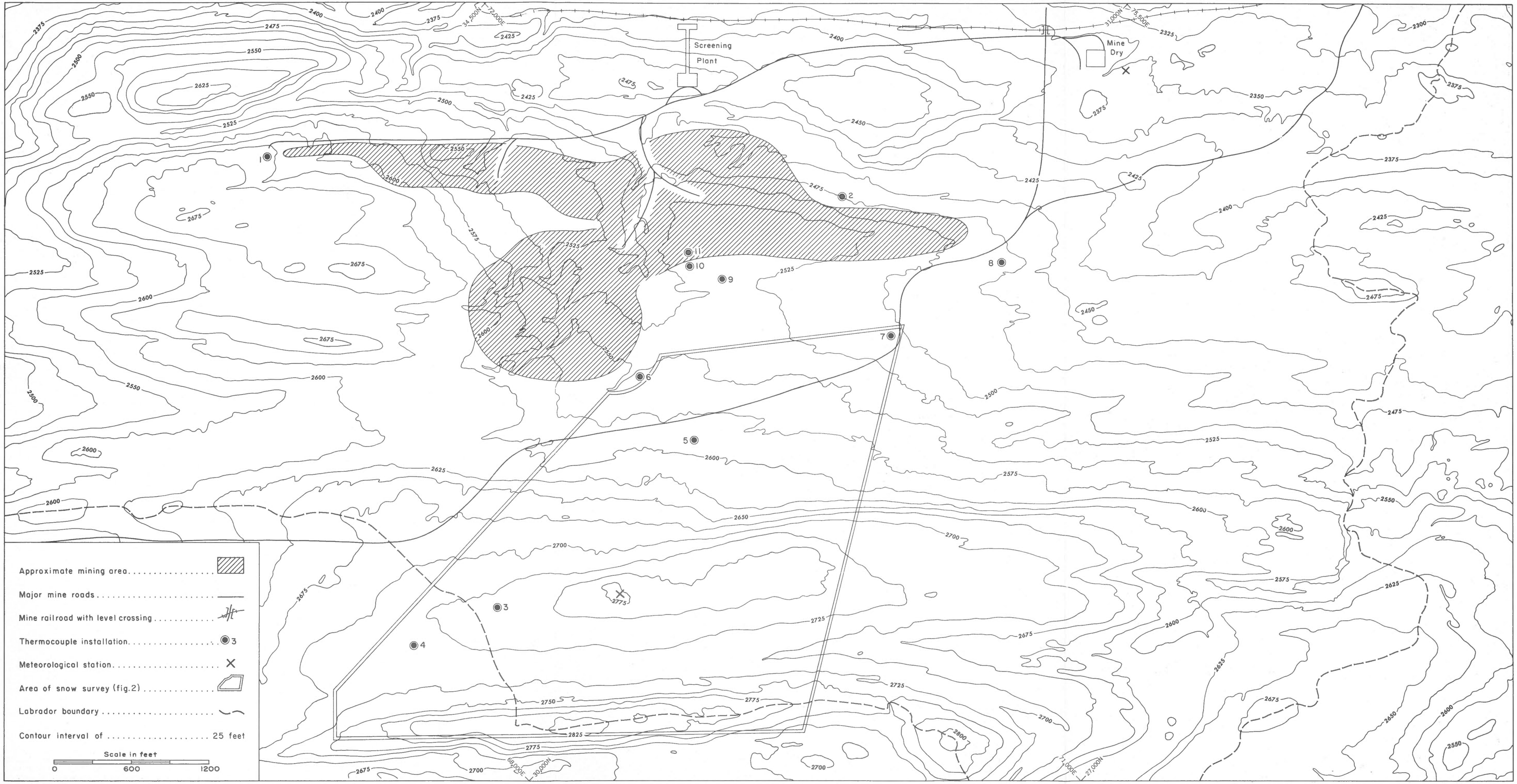

Figure 3 Topography and research installation of the Ferriman mine area near Schefferville. (Contour interval, 25 feet).

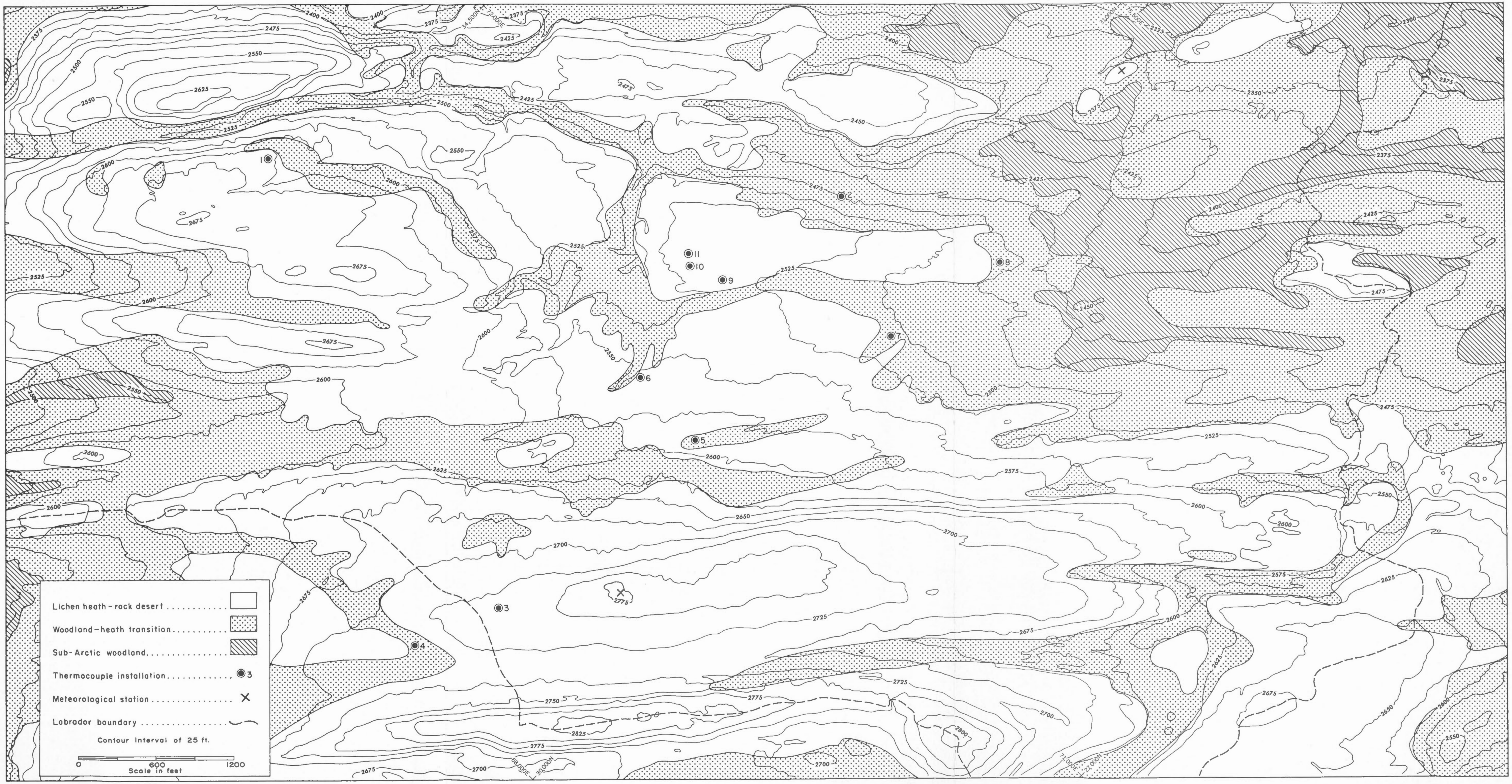

Figure 4 Distribution of cover types in the Ferriman mine area near Schefferville. (Mapping from field observations and airphoto interpretation).

hollow. The contrast in exposure with site 3 was strong, with thick lichen clumps and scattered sedges and mosses forming the ground mat. Occasional spruce clumps, with a maximum height of 5 feet grew in the immediate vicinity, together with willow and birch scrub. The special site characteristics clearly formed a small outlier of the woodland-heath transition zone (Figure 15). Heavy snow accumulation was anticipated and the need for comparison of ground temperature conditions with those at site 3 was clearly indicated.

Site 5. A 50-foot string of thermocouples was installed on 16th July at an altitude of 2,317 feet. The site chosen formed part of a slight depression 10 to 18 feet deep, formed in a zone of weak rocks below the base of the main Ferriman ridge. Vegetation varied from Cladonia lichens on the drier parts to sedges and mosses on the lower ground. Scattered willow and birch scrub occurred, together with occasional spruce trees. This site again lay in a small outlier of the woodland-heath transition zone and heavy snow accumulation was anticipated.

Site 6. Installation was effected to a depth of 74 feet at an elevation of 2,280 feet in early September. The site was part of a broad tract of open, gently undulating ground towards the lower limit of the lichen-heath zone. The upper sentinels of the tree line were situated downslope at a distance of 60 to 80 yards. Moderate to slight snow accumulation was expected.

Site 7. Although this string had been installed in September 1957 to a depth of 150 feet no previous temperature readings had been taken. Its site characteristics, however, proved ideal for the present study. Altitude was 2,235 feet, at the base of a broad hollow, giving heavy snow accumulation in the upper fringe of the woodland-heath transition zone.

Site 8. This final set of the summer installation program was effected to a depth of 79 feet on 17th September, sited on a slight rise on the fringe of the sub-arctic woodland zone at an elevation of 2,220 feet. Spruce trees, 8 to 20 feet high, occurred in the general area, but the immediate site was occupied by a thick mat of Cladonia lichens. Downslope to the southeast, the trees rapidly thickened to form a regular black spruce forest (Figure 16).

Site 9. Installation was effected on 23rd December to a depth of 60 feet. The site was on level ground from which the surface material had been stripped during the previous summer. It was at an elevation of 2,362 feet and about 200 feet from the existing pit limit. The original surface had been covered by a thick lichen mat in an area of moderate to slight snow accumulation.

Site 10. This string of thermocouples was sited on 27th December 12 feet from the pit wall, as close as drilling operations would allow. A depth of 60 feet was attained at an elevation of 2,360 feet. The site characteristics were essentially similar to those of site 9 with the exception of the proximity to the pit wall. It was hoped to evaluate the effect of this on the ground temperature regime.

Site 11. The final set was located immediately below site 10 on the floor of the first burm of the pit. The upper 28 feet of overburden and ore had been excavated so that the actual elevation of the site was 2,332 feet. Thermocouples were installed to a depth of 60 feet on 28th December. This site, in the lee of the 28-foot pit wall was expected to accumulate a large snow drift.

Method of installation and instrumentation

Copper-constantan thermocouples, bound together with electric tape, were installed in diamond and rotary drill-holes. After completion of diamond drilling, the rods were withdrawn, leaving the casing in place. The thermocouple string was then weighted and lowered into the hole, after which the hole was filled with oven-dried sand. As much as 150 lb. of sand per 10 feet of fill was required, and great care was taken to avoid the formation of air pockets in the hole. The casing was withdrawn, segment by segment, as additional sand was added. This apparently simple operation posed many difficulties, particularly when the hole did not penetrate to the base of the permafrost and remained filled with water. In this case, sand accumulated around irregularities in the thermocouple string and often caused it to lock within the drill casing. This accounts for the irregular depths of the thermocouples as depth was lost when the casing was pulled in an effort to break a lockage. If this loss was more than a few feet, the thermocouples were withdrawn, the hole rebored, and the installation process begun over again. In the case of rotary drill holes, installation was much more simple as no water was necessary for drilling operations and a dry hole resulted. Care had to be taken to effect installation of thermocouples before the thawing active layer slumped into the hole, although this never caused any real difficulty.

Ten-foot leads were provided for, and each lead was tagged with a metal plate for identification. The leads were then connected to a rotary switch which was installed in a small, unheated shack, located down wind of each site. The cable projecting above ground level was securely bound with rubberized tape to protect the thermocouple leads against the weather. Each site was carefully surveyed by mining engineers and located on a topographical map scale 1:4,800 with a 5-foot contour interval. The map was used as the general base map for the project. In practice it was found that 20-foot leads would have been more suitable as the shacks could then have been located at a greater distance from the actual site. This in turn would have helped to avoid unnatural snow drifting due to the proximity of the shack.

This type of thermocouple installation is admittedly a rough and ready method which could be greatly improved, although it is probably adequate for a relatively short-term program. Circumstances of the drilling program demanded rapid installation, but the narrow margin of error in the results obtained

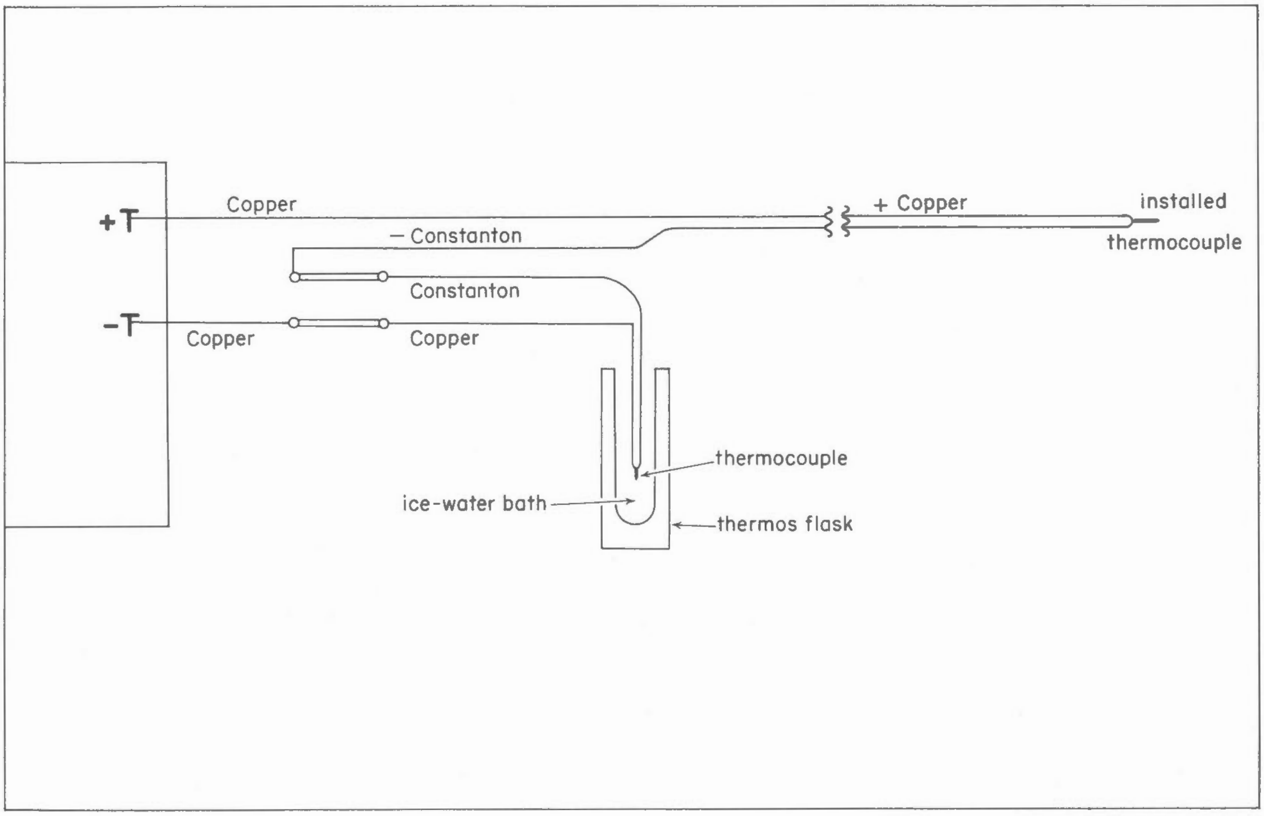

Figure 5 Circuit extension for the potentiometer.

was gratifying.

Electromotive force (EMF) measurements were read on Leeds and Northrup portable precision potentiometer No. 8662 with external standard cell and ice-water bath for the reference junction (Figure 5). Initial experiments under laboratory conditions revealed an accuracy of $\pm .05^{\circ}$, actually the limit of accuracy in reading the thermometer used in the temperature baths. As this order of accuracy was more than adequate for the first stage of the program, there remained only the precise assessment of the margin of error involved in actual field work.

There are a number of problems involved in using a potentiometer in the field and these are outlined for the benefit of those without practical experience. The problems are largely related to weather conditions affecting the temperature of the instrument and the terminals. Changing the temperature of the potentiometer naturally causes resistance changes within the instrument, and this should be avoided as far as possible. Thus, the unheated shacks were used to keep the potentiometer from the direct rays of the sun and to reduce difficulties due to wind, which causes fluctuations of the galvanometer balance needle and makes accurate reading difficult. Because of this, periods in the day with fairly stable air temperatures and calm conditions were chosen. In addition, slight fluctuations in temperature of the ice-water bath used as a reference junction were found to be a potential source of error. In this case, a thermos flask was used for the bath and repeated temperature readings were taken on a standard mercury thermometer throughout the operation.

During the summer these simple precautions resulted in an accuracy of $\pm .2^{\circ}F$. This result was obtained by cross-checking thermocouple readings by repeated re-reading after intervals of 30 minutes to 2 hours. Winter conditions proved much more difficult, however, and the degree of accuracy was correspondingly smaller, although the practical problems were the same. In addition, the standard cell and ice-water bath had to be kept from freezing. The dry cells used to power the pilot light and potentiometer were mounted in a wooden box insulated with fibre glass. The standard cell was inserted in the box at temperatures above $20^{\circ}F.$, but at lower temperatures was carried by the observer in an inside pocket of especially insulated clothing. The ice-water bath was also carried in the box on journeys between stations and taken out during the short observation period.

Most of the thermocouple sites were situated away from the mine access roads which were kept open in winter. Thus the equipment had to be carried to the site on skis or snowshoes for distances of up to a mile. As the equipment weighed approximately 70 lb., and progress was often slow due to snow and weather conditions, this resulted in a considerable loss of heat despite the insulation, especially at low temperatures. In general practice, one trip was made with the potentiometer, less standard cell and ice-water bath. Those shacks in heavy snow accumulation areas were dug out, in late winter to a depth of as much as 7 feet, and the potentiometer partially set up. The instrument was then left for 2 or 3 hours to allow its temperature to become stabilized. Then a rapid journey was made on skis with the insulated equipment, and the readings were taken. Under these conditions it was rarely possible to read more than two strings of thermocouples in the course of one day and a sudden increase of wind speed for instance would make it impossible to obtain accurate readings on the more exposed sites.

To gauge possible errors, the deeper thermocouples were read on all occasions and, as it could be assumed that below 15 feet practically no change in ground temperature would occur over a period of

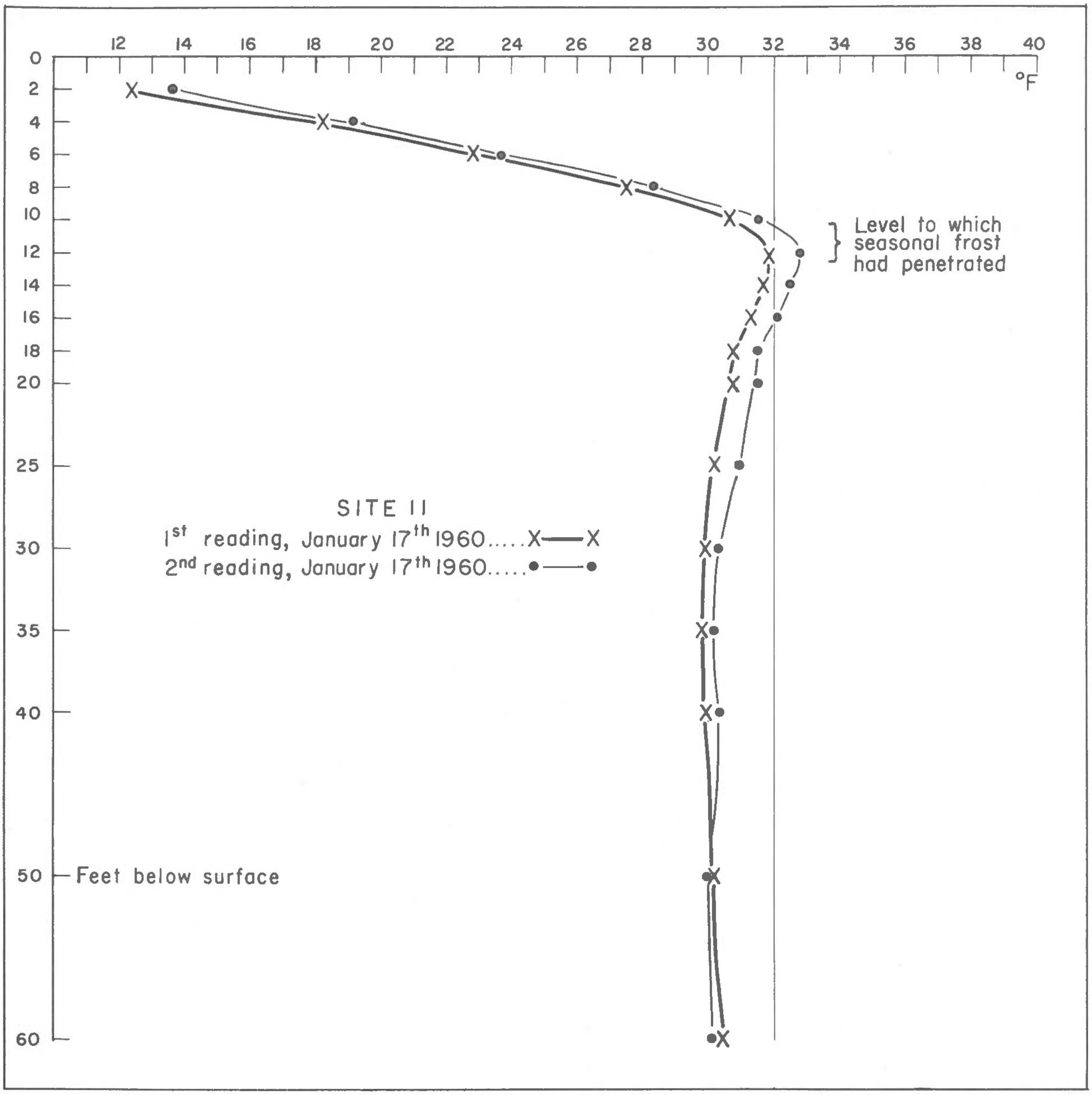

Figure 6 To illustrate the margin of error during winter operations. The two sets of readings were taken within a 2½-hour period. Despite the error, it is apparent that seasonal "frost penetration", calculated from either curve, will give effectively the same result.

several weeks, all readings were disregarded unless reasonable correlation was obtained.

During winter work the human element became very important. Working in temperature conditions below zero proved trying, and 30 minutes in a sitting position at each site, after a warm and strenuous journey up hill in insulated clothing resulted in heavy perspiration, followed by rapid cooling. All small tools,

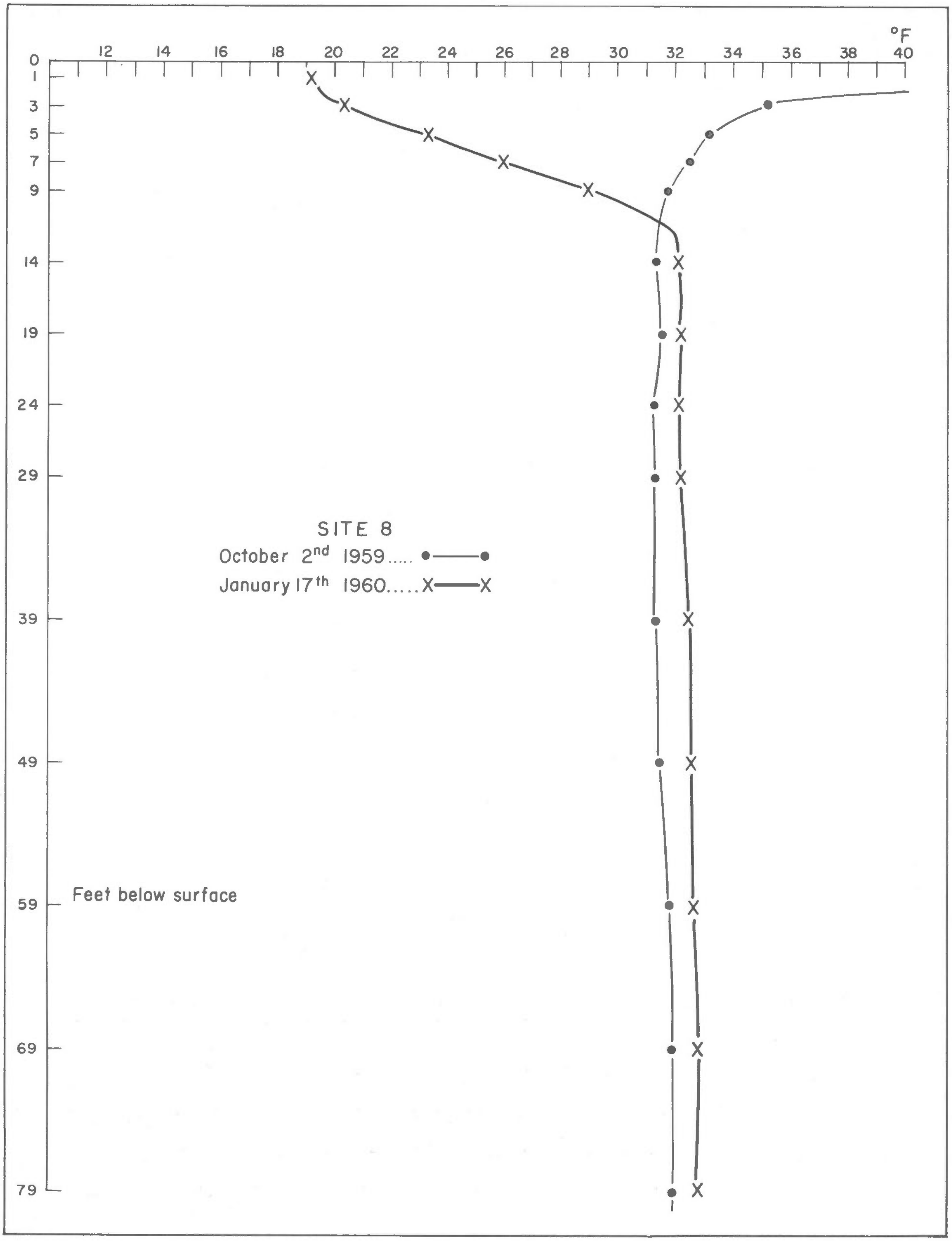

Figure 7 To illustrate the margin of error by comparing potentiometer readings on the same thermocouple string in October and January. Here the situation is particularly critical because the error is "spread across" the 32°F. line.

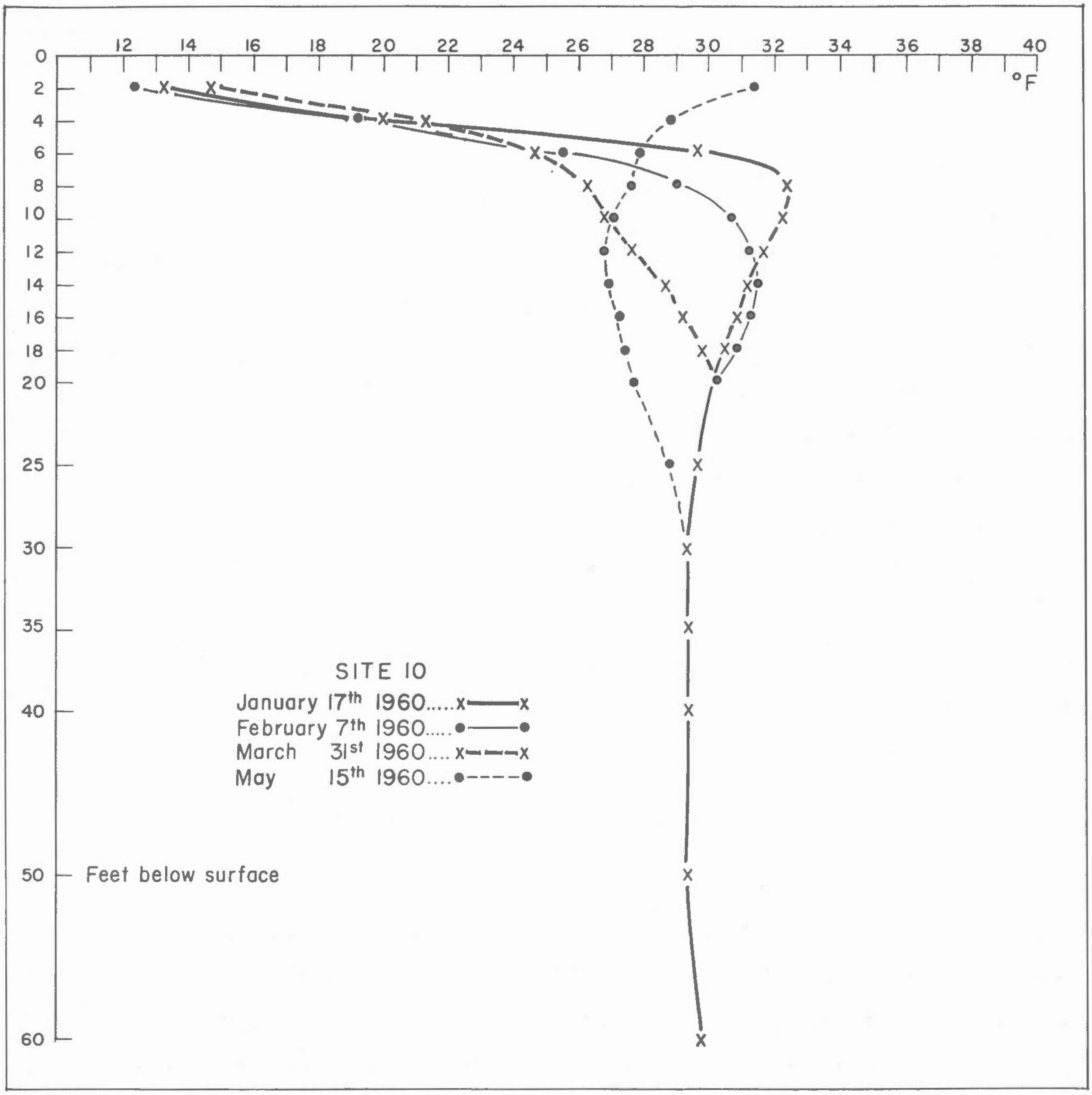

Figure 8 To illustrate ground temperature trends during the first five months of 1960. By May 15th the surface was water-logged.

such as screw drivers and pliers, were bound in plastic tape, and silk gloves proved very useful; however, many of the electrical contacts had to be made with bare hands and it was sometimes impossible to avoid freezing the finger tips. It was found that in air temperatures of - 10°F. and below, the low accuracy of the results did not justify the effort involved. It was found impossible to complete the originally intended schedule of bi-monthly readings at all sites, although monthly readings were obtained. In January and February, with mean monthly air temperatures of - 10.4 and - 5.6°F., respectively, the anomalous periods of freezing rain and relatively high temperatures in 1960 enabled completion of the monthly schedule. The margin of error during winter operations was calculated at ± 0.7°F. When it is considered that large sections of the local permafrost have a temperature of between 31.0 and 32.0°F. a possible maximum error of one degree is most unsatisfactory. However, the winter work was primarily concerned with measuring temperature changes in the upper 15 feet and as these were very large, the effect of this error was barely noticeable when the results were plotted. As a measure of heat loss from the upper layers (i.e., frost penetration), the nature of the temperature/depth curves allowed a very accurate estimate, despite the magnitude of the error. It was readily apparent that the excellent "fit" of the data on the curves drawn allowed a precise estimate of the penetration of the winter temperature wave, even if absolute temperatures were in error by as much as 1°F. (see Figures 6, 7, 8).

From this experience it was realized that the standard ground temperatures at depth should be obtained during optimum conditions in summer, while in winter, relative temperatures in the upper layers would be adequate for a preliminary assessment of conditions. Future development of the study, which should involve an attempt to measure precisely the geothermal gradient and to compute the total energy exchange through the different surface types, would demand much more elaborate instrumentation.

METEOROLOGICAL INSTALLATIONS AND OBSERVATIONS

Two Stevenson's screens, each with maximum and minimum thermometers and thermographs were set up to standard Department of Transport specifications in June 1959. One was located at the Ferriman mine dry at an elevation of 2,103 feet, where the site is representative of the southern mine area and the lower ground at, or just below, the "tree line".* Here also a self-recording anemometer was located 15 feet above the roof of the mine dry from which the leads were led to a daily recording clock assembly in the main office below. The second station was located on the high ridge crest to the west at an elevation of 2,510 feet and within 300 yards of the most exposed thermocouple string (see Figure 3). This site provides maximum elevation and exposure conditions, the two stations together giving a measure of the extremes to be anticipated in the area under study. Simple counting anemometers were set up at this second station

*In fact there is no marked altitudinal limit to tree growth, rather a wide zone through which the trees become stunted, widely spaced, and ultimately disappear.

because a self-recording design with a daily chart was not practicable due to inaccessibility in winter.

The objective of the meteorological installation was to provide mean annual air temperatures and wind speeds for comparison across the project area and with the standard records of the McGill Sub-Arctic Research Laboratory a first-order Department of Transport weather observing station, located 5 miles away.

In practice it proved possible to maintain readings at the two stations only on a weekly basis throughout the winter. In addition many difficulties, only partially overcome, led to reduction in the value of the observations. In particular, the thermograph clocks and anemometers stopped periodically due to heavy icing conditions prevalent for much of November, December and January. Also, periods of heavy snow drift caused plugging of the screens and a resulting stoppage of the thermograph clocks. Weekly maximum and minimum temperatures were obtained, however, throughout the period July 1st 1959 to August 1st 1960, together with a large proportion of the thermograph trace. While this can only provide an approximation to the actual mean annual temperatures and the degree of accuracy is not more than - 1°F., comparison of individual maximum and minimum temperatures with those recorded at the McGill Sub-Arctic Research Laboratory indicate that mean winter temperatures increase with height above the valley floors, while the reverse holds true in summer. The extreme case occurred in November when the minimum temperature recorded at the Laboratory was - 27°F. (alt. 1,665 ft.), compared with - 11°F. at the ridge crest (alt. 2,510 ft.).

It was particularly significant to note that an annual mean temperature of 23.9°F. in the Schefferville townsite area at an elevation of less than 1,700 feet is not accompanied by permafrost development, whereas an annual mean temperature probably little lower than this on the ridge crests is accompanied by permafrost more than 250 feet thick. One of the reasons is that lower summer temperatures on the ridge crest, due to elevation and increased cloudiness, results in reduced heat flow into the ground, whereas little or no snow cover in winter, even with higher temperatures due to inversions, results in more rapid heat loss. This illustrates forcibly the difficulty of generalizing from individual elements, a matter of considerable importance when many of the existing estimates of the southern permafrost boundary are based upon the mean annual temperature charts.

SNOW SURVEY

In early winter, mid-winter and late winter detailed surveys were made of the snow accumulation across a large sample tract of the project area (Figures 2 and 3). These surveys involved actual snow-depth measurements on a closely-spaced graticule in the area most densely covered by thermocouple installation. Sufficient detail was obtained to compile three reliable maps of snow depth, that provide a good picture of the mode and rate of snow accumulation throughout the winter. This was further supplemented by snow-depth measurements at each of the thermocouple sites during routine visits.

As snow depth is perhaps the main factor involved in heat loss from the ground during winter, correlation between ground temperature regime and snow depth should be vital in any attempt to estimate permafrost conditions in a marginal area of varied relief and vegetation, such as central Labrador-Ungava. Vegetation is believed to be of importance partly because of its direct insulating properties, but more particularly because of the influence upon snow accumulation and because it provides a precise guide to snow depth in winter (Dahl, 1956).

CLASSIFICATION AND MAPPING OF VEGETATION

A simple physiognomic classification of the vegetation or cover types was used (see Hare, 1959 p. 24), because the objective was to provide indices of exposure and snow accumulation and the over-all bearing of the nature of the surface on the ground temperature regime. With increasingly detailed knowledge of ground temperature conditions it is hoped that a study of the combination of cover type and relief will allow good provisional estimates to be made of ground temperature conditions across wide areas of the sub-arctic for which no ground temperature measurements exist.

Within the study area three cover types were defined and mapped. After careful airphoto interpretation in the field the main mapping project was done in the office from airphotos on the scale of 1:12,000. The data was plotted directly on to the base map on the scale of 1:4,800 (Figure 4):

(a) Lichen heath - rock desert (Figure 14) - This rather broad category embraces the area of tundra proper and is confined to the upper and more exposed areas making up almost two-thirds of the map-area. It ranges from a thick carpet of Cladonia lichens in the more sheltered areas to bare, shattered rock with rock lichens and scattered plants in the crevices, occupying the ridge crests. An intermediate type is represented by a broken cover of Cladonia lichens interspersed with wide areas of stony earth circles. This type usually occurs on gently convex hill slopes exposed to the wind.

The main unifying factor of this category is that it has little effect on the process of anchoring drifting snow. This is not to say that the lichen heath-rock desert zone is characterized by slight snow accumulation, however, since purely relief-controlled drifting is an equally important factor.

(b) Sub-arctic woodland (Figure 11) - In the Ferriman Mine area the sub-arctic woodland type falls largely within Hare's open lichen-woodland and open lichen-shrub-woodland types (Hare, 1959 p. 26), although small patches of closed-crown forest do occur (Figure 13). Black spruce is the dominant tree, but white spruce and tamarak occur. The dominant shrub is birch (betula glandulosa) although willow (salix spp.) also occurs. This division is important in that it denotes low relative elevation and sheltered location, and uniformly deep snow is characteristic.

(c) Woodland-heath transition (Figure 12) - This, in effect, represents the "treeline" zone. It is characterized by small stunted spruce, widely scattered, together with scattered clumps, and in some cases, thickets of birch and willow shrub (Figure 16). Occasional outliers of this zone lie at relatively great altitudes in the lee of ridge crests and in slight hollows. Five or six stunted spruce clumps may occur, together with scattered clumps of birch. These areas are significant as they indicate relative shelter from prevailing winds and relatively heavy snow accumulation.

Figure 4 shows the distribution of the three cover types in relation to the thermocouple installation; Figure 9 gives a characteristic impression of the gradation from one zone to the next on a fairly uniform slope.

DISCUSSION

While much more data are required, and much work remains to be done on the data already collected, it is tentatively concluded that there is a significant correlation between vegetation cover, relief, snow depth and ground temperature regime in central Labrador-Ungava. In this sense, to use an extreme case for illustration, it is believed that areas of lichen heath-rock desert with slight snow coverage in winter will be underlain by permafrost of considerable thickness. On this basis alone, permafrost may be expected to occur as far south as the Laurentide Scarp wherever hilltops rise above the tree line. Although outside the area under consideration, it is also probable that permafrost will be present beneath the higher summits of the Notre Dame Mountains south of the Gulf of St. Lawrence. In the sense implied here, the permafrost is not relic, but is compatible with existing conditions. The difficulties of permafrost prediction increase greatly, however, in the areas below the tree line. These are essentially the areas of scattered, relic permafrost.

By definition, relic permafrost developed under climatic and/or surface conditions differing from those of today, so that direct prediction of its occurrence from a study of present-day conditions is illogical. It is logical, however, to suggest that relic permafrost is most likely to occur in those areas close to the tree line, although on theoretical grounds its distribution is probably much more extensive than implied here. Wide areas of burned-over woodland occur throughout the entire area and further complicate the problem.

While considerable super-cooling of the ground is necessary before freezing occurs, laboratory work is indicating with more and more certainty (Williams, personal communication), that thawing will only occur when the ground temperature rises above 32°F. This factor, added to the importance of the latent heat of fusion, indicates that the natural degeneration of permafrost is a very lengthy process. Given the same mean annual air temperature in central Labrador-Ungava as today, and total absence of arboreal vegetation, it seems highly probable that permafrost would be extremely widespread. These conditions probably occurred immediately after deglaciation about 7,000 to 9,000 years ago. The evolution of the forests, inducing also added snow accumulation, would then serve to change radically the balance of the ground/air temperature regime and in particular, the ratio of the mean ground temperature to the mean air temperature. Thus large areas of permafrost, beneath a newly-established tree line, would degenerate and, with the passage of time, result in the existence of widely scattered residual masses. Hypothetically, therefore, it is understandable that relic permafrost is not necessarily explained by invoking a former colder climate, but is rather the result of changing vegetation conditions following deglaciation. Consequently, scattered patches of relic permafrost are expected to occur throughout south-central Labrador-Ungava, a fact which must always be borne in mind when attempting to map permafrost distribution from existing conditions.

CONCLUSION

The research program and the details on the preliminary investigations, presented above, have been governed entirely by the objectives of pure research. Although it is almost accidental that such a program should be closely related to the economics of mining iron ore, it is quite obvious that this relationship has resulted in the very costly support that the fundamental thermocouple installation required. It is also gratifying to realize that pure research and direct application to mining problems are so closely related.

Mining costs in permanently frozen ore were estimated at almost three times those of mining under normal conditions. The greater expense is incurred by the difficulties of blasting permafrost, an essentially quasi-elastic material when the water content is higher than 5-7%; by the problems of removing the broken material, which is frequently in large blocks that cannot be handled directly; by the difficulties of expanding the pits and maintaining their physical conditions conducive to the deployment of heavy equipment; and to the multitude of problems associated with the process of passing frozen ore through the screening plants and of carrying it by train and ship, in a thawing condition, into areas of higher temperatures.

A great improvement in blasting techniques has already been effected by staff of the Iron Ore Company of Canada, although the essential problems still remain. A broader consideration is the long-term planning of ore extraction in areas where ground temperature conditions are unknown. Mining concerns in potential permafrost areas would profit from basing long-term cost estimates on a reasonably precise knowledge of the proportion of frozen to unfrozen ore. In this respect fulfillment of the over-all objective of this research project, if it provides a very low cost method of estimating permafrost occurrence, should more than justify the effort involved.

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MS. Submitted 30 November, 1960

Figure 9 General landscape of the Ferriman mine area looking southeastwards from the "West Ridge" across the three vegetation zones.

Figure 10 General landscape looking north-by-east across one of the main mining areas.

Figure 11 Subarctic woodland of relatively rich growth in valley bottom to the southeast of the map-area. Note the dense growth of birch scrub in the foreground and the gradual thinning out of the spruce in the "tree-line zone" on the far hillside.

Figure 12 Woodland-heath transition zone showing wide areas of birch scrub that demarcate the limit of heavy winter snow accumulation. Cladonia lichens in the foreground and a small area of relatively dense subarctic woodland in far left. View towards the south-southeast.

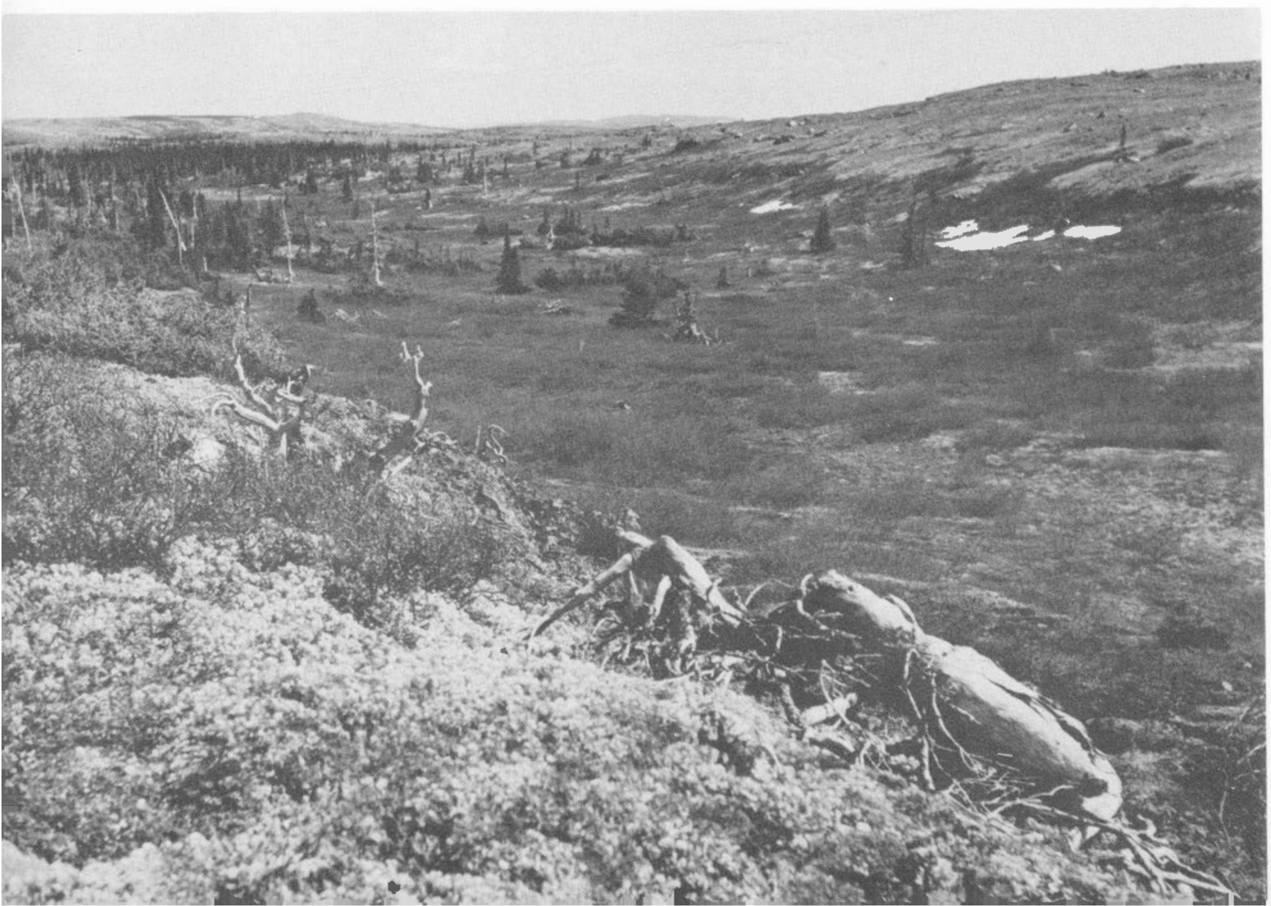

Figure 13 A small outlier of the woodland-heath transition zone just below and in the lee of the "West Ridge" crest. This area of relatively heavy snow accumulation shows a richer sedge and lichen vegetation and scattered spruce trees with a marked wind gap indicating the position of the winter snow surface.

Figure 14 The lichen heath-rock desert zone looking west-northwestwards from the high-level meteorological station. The shack adjacent to thermocouple site No. 3 can be seen in the angle of the anemometer supports.

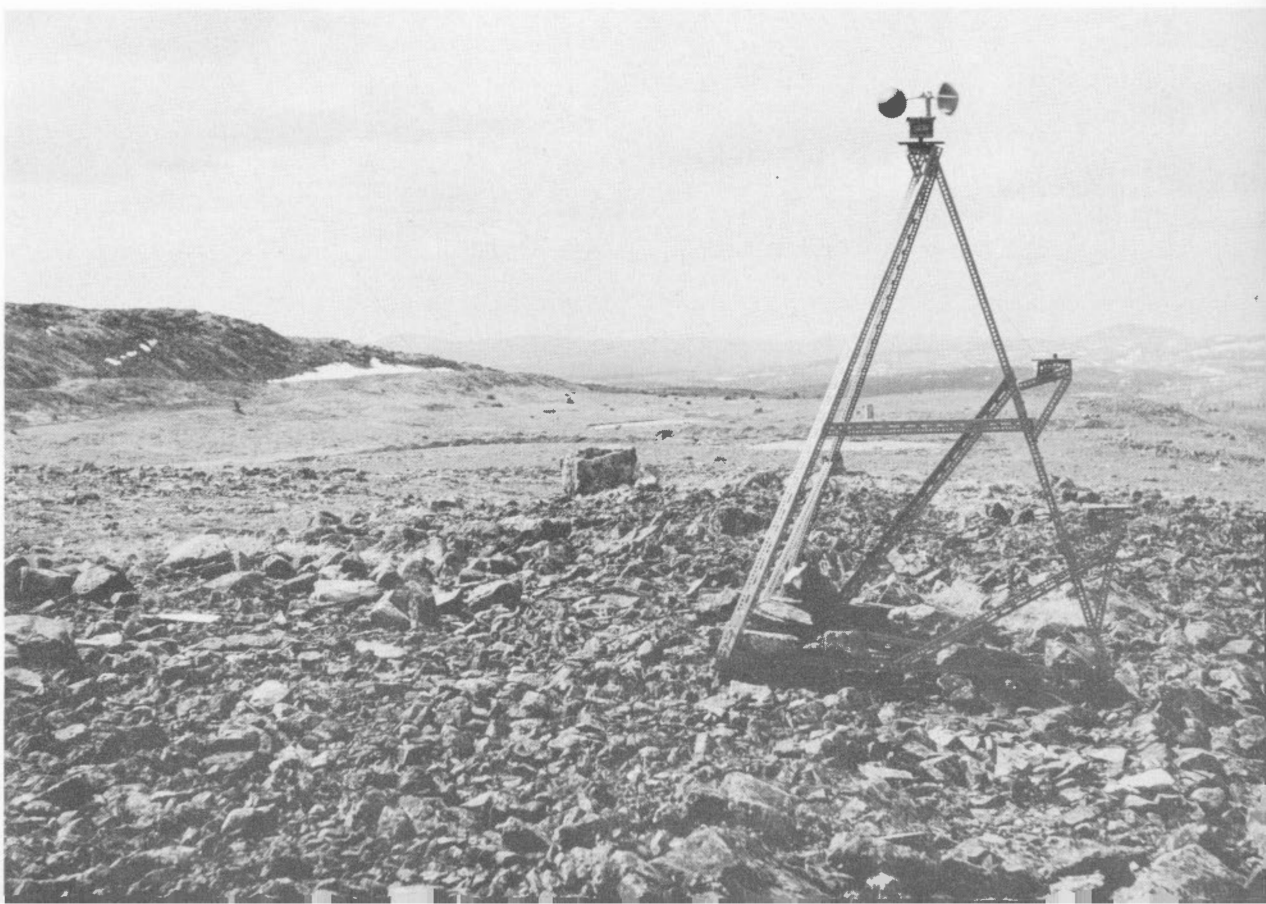

Figure 15 The general site characteristics of thermocouple string No. 4. Note the narrow zone of woodland-heath transition vegetation which is believed to demarcate an area of unfrozen ground surrounded by permafrost exceeding 250 feet in thickness. The broken lichen mat with stony earth circles in the foreground represents an area of very scanty snow accumulation.

Figure 16 The site of thermocouple string No. 8 showing large, widely scattered spruce with pronounced wind gaps. Note the dense birch and rich lichen carpet in the foreground. Photo taken in early summer shortly after the disappearance of the snow. The cab of the Land Rover can be seen to the right of the shack, giving scale.

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