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Pihlainen, J. A.

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Guide to a Field Description of Permafrost for Engineering Purposes

Pihlainen, J.A.

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Section 4

GUIDE

to a

FIELD DESCRIPTION

of

PERMAFROST

for

Engineering Purposes

INTRODUCTION

Almost one half of Canada's total land surface is underlain by permafrost and its existence has many implications to both scientific and engineering interests. Engineering experience has indicated that site investigations are essential in permafrost areas but no standard method for reporting permafrost conditions has been used or is available. This booklet has been prepared with the hope that the descriptive system outlined will fulfil this need.

The method for describing the ice phase in perennially frozen materials, which forms a major part of this "Guide", was originally developed by the Arctic Construction and Frost Effects Laboratory (now Cold Regions Research and Engineering Laboratories) of the U.S. Corps of Engineers, with assistance from the Division of Building Research, National Research Council, Canada. It is intended that the booklets on Soils (Technical Memorandum 37) and Muskeg (Technical Memorandum 44) previously published by the Associate Committee on Soil and Snow Mechanics be used as companions to this Guide.

Comments and criticism regarding the usefulness of this suggested descriptive system for permafrost are encouraged and will be welcomed.

Section 4

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1. WHAT IS MEANT BY "PERMAFROST"

Permafrost is defined as the thermal condition under which earth materials exist at a temperature below 32°F continuously for a number of years. Thus, all earth materials including bedrock, gravel, sand, silt, peat or mixtures of these materials may exist in the perennially below 32°F condition. Permafrost is defined exclusively on the basis of temperature, irrespective of texture, degree of induration, water content or lithologic character.

The term "perennially frozen", although cumbersome, is generally used to describe specific perennially frozen materials, e.g. perennially frozen silt, perennially frozen organic material. The presence of ice is not a necessary requisite of permafrost, but when ice is present it is of particular significance to engineers.

The term permafrost can also be used to describe the areal extent of the below 32°F condition. It has been found convenient to divide the permafrost region into two major zones—the continuous and the discontinuous. In the *continuous* zone permafrost is found everywhere under the ground surface to considerable depth; in the *discontinuous* zone permafrost is not as thick and exists in combination with areas of unfrozen material.

2. BASIS OF THE DESCRIPTIVE SYSTEM

Although permafrost is defined on a temperature basis, temperature is not a convenient or easily measured property for field description purposes. A more convenient approach to the field description of permafrost is to describe terrain features that may influence the existence of permafrost. Observations of terrain and the effects of construction on permafrost in northern Canada have suggested the following specific features of terrain that are of interest to engineers:

(1) Surface characteristics
    Vegetation cover
    Snow cover
    Relief and drainage

(2) Subsurface characteristics
  Depth of thaw
  Subsurface materials
    Soil phase
    Ice phase

Observations on these topics represent a minimum of field information that must be collected to describe permafrost adequately for an engineering appraisal of a site.

3. SURFACE CHARACTERISTICS

3.1 Vegetation Cover

The vegetative mantle of trees, shrubs, moss, lichen and other plants that covers much of the North acts as an insulator that protects and maintains permafrost. Vegetative cover is of additional interest in that it may indicate soil, ground water, wind and/or snow conditions. The major combinations of vegetation at a site should be delineated and described using the system outlined in the "Guide to a Field Description of Muskeg" (Technical Memorandum 44) published by the Associate Committee on Soil and Snow Mechanics.

3.2 Snow Cover

Although snow is basically a part of the climate, snow cover is generally considered as a terrain factor. The presence of snow reduces the depth of seasonal frost penetration during the winter and conversely inhibits thawing of frozen material in the spring. The type of snow, the depth of snow cover and their variability over a site throughout the winter season should therefore be observed.

3.3 Relief and Drainage

Terrain relief influences permafrost occurrence and since it is also a significant factor in drainage it is an important engineering consideration. Regional relief features should be described in addition to those observed at specific locations under investigation. Regional descriptions should include some indication of altitudes; whether the landscape is mountainous, hilly, undulating or flat; possible origin of the landform; and the regional drainage pattern. At specific sites small scale or micro features of relief and drainage should be noted. These small scale features are difficult to classify for descriptive purposes but would include details of patterned ground (sorted or unsorted circles, nets, polygons, steps and stripes), micro-drainage, slope and exposure to solar radiation.

A photographic record of the various surface characteristics (e.g. showing typical vegetation and snow cover, and relief and drainage features) is most valuable. A complete description of site conditions can be usefully summarized on a sketch map or air photograph of the area under investigation.

4. SUBSURFACE CHARACTERISTICS

4.1 Depth of Thaw

The seasonal depth of thaw and its variability within an area and from year to year has long been recognized as an important engineering consideration in permafrost areas. The depth of thaw refers to that portion below the ground surface at a specific location that is thawed at some time during the course of a summer. It increases progressively during the thawing season and therefore it is important to note the date on which a particular observation was made. When the seasonal thaw has reached its maximum depth (usually in the late fall) it then corresponds to the *"active layer"*. The *"active layer"* refers to the zone in which seasonal thawing *and* freezing occurs.

The depth and rate of thaw are affected by and closely related to terrain features. Any variations in an area are usually the result of differences in surface conditions such as vegetation, relief, drainage and snow cover and may also be related to changes in subsurface materials.

Initially, depth of thaw observations should be made in areas having different surface covers and then extended to locations within these areas that have noticeable changes in relief, drainage or subsurface materials. Appreciable differences in the depth of thaw for an area as small as 5 feet square are possible. It is important therefore to make many random observations at a site and to record not only the average but also the maximum and minimum depths of thaw for the area.

The depth of thaw can be conveniently measured using a probe that retains a sample of the thawed subsurface materials for examination. Records of the depth of thaw should also include notes on the date of observation, vegetation cover, relief, drainage, and a description of the subsurface materials in the various areas probed. Some assessment of the moisture content, density and ice segregation in the frozen soil underlying the thawed zone are of particular interest.

4.2 Subsurface Materials

The materials encountered in the frozen state vary, and can include bedrock, gravel, sand, silt, clay and organic material (peat). These frozen materials or combinations of them frequently contain considerable quantities of ice. Important engineering implications are involved when this condition occurs. It is important, therefore, to examine not only the soil but also the ice encountered in the soil. For engineering purposes, it is convenient to describe the soil and ice phases independently. At times a description of frozen bedrock may be required. It will be noted in the following paragraphs that the ice description system is based on the form of ice in frozen materials and is therefore applicable for either soils or bedrock.

4.2.1 Soil phase

The description of the soil phase applies to materials found in both the thawed and frozen states. Coarse- and fine-grained soils should be described according to the "Guide to a Field Description of Soils" (Technical Memorandum 37) published by the Associate Committee on Soil and Snow Mechanics. Partly organic soils, which are largely mineral types, are described as the predominant soil modified by the word "organic", e.g. organic silt. Soils that are mostly organic (peat), however, should be described according to the system outlined in "Guide to a Field Description of Muskeg" (Technical Memorandum 44).

4.2.2 Ice phase

The descriptive system for the ice phase is based on the *form* of ice found in frozen materials. It is not intended that this system be used to assess frozen materials according to properties or performance.

For descriptive purposes frozen materials are divided into three major groups in which the ice is:

not visible by eye,

visible by eye with individual ice layers *less* than 1 inch in thickness,

visible by eye with individual ice layers *greater* than 1 inch in thickness.

The major ice phase descriptive groups and their subdivisions are summarized in Table I. Letter symbols that suggest key descriptive terms of the ice forms for each subdivision have been included to help in the preparation of graphic logs or records. Written observations, however, are the fundamental feature of the descriptive system and the letter designations must be regarded only as a "shorthand" form. Guides for further descriptive details and illustrations of the basic types are included. It is not expected or intended that all of the detail shown in Table I should always be noted. In much engineering work only the most fundamental details need be recorded. Some definitions to clarify terms used in the ice phase descriptive system are given in Table II.

(*A*) *Ice not visible*

When ice is not discernible by eye its effectiveness as a cementing agent in bonding the mineral or organic portion is used as a further subdivision:

(a) ice that bonds or cements the subsurface materials into a *weak or friable mass,*

(b) ice that bonds the subsurface material into a *hard, solid mass.*

The presence of ice not generally discernible by eye may be revealed within the voids of the material by crystal reflections or by a sheen on fractured or trimmed surfaces. The impression to the unaided eye is that none of the frozen water occupies space in excess of the original voids in the soil. The opposite is true of soils where the ice segregation is visible by eye.

In some cases, particularly in materials well bonded by ice, a large portion of the material may actually be ice, even though it is not discernible by eye. When visual methods are inadequate, a simple field test to aid evaluation of the volume of excess ice can be made by placing a chunk of the material in a small jar, allowing it to thaw, and observing the quantity of water as a percentage of the total volume. If free water is noted it is termed "excess".

(*B*) *Visible ice segregation less than 1 inch thick*

When ice is discernible by eye and is less than 1 inch thick further subdivision is based on the form and orientation of the ice concentrations:

(a) individual ice crystals or inclusions,

(b) ice coatings on particles,

(c) random or irregularly oriented ice formations,

(d) stratified or distinctly oriented ice formations.

(*C*) *Visible ice segregation greater than 1 inch thick*

For descriptive purposes, ice formations greater than 1 inch thick may be considered as ICE. Two types of ice strata are recognized at present:

(a) ice with soil inclusions,

(b) ice without soil inclusions.

In some cases the occurrence of stratified or distinctly oriented ice formations in frozen soil increases to such an extent that the frozen material approaches "ice with silt lenses". Although the absence or inclusion of soil in ice is a first subdivision, the over-all form of the ice mass should also be included. Common forms of such "massive ice" are:

random or irregularly oriented layers, vertical, wedge-shaped sheets, and variable chunks or blocks sometimes hundreds of square feet in area.

5. FIELD INVESTIGATIONS AND RECORDS

The scope of field investigations of permafrost and the amount and type of information required will depend largely upon the use for which it is intended. A discontinuity in the occurrence of permafrost (areas free of permafrost or large variations in the depth to permafrost) has many implications to construction. Accordingly, a sufficient number of observations must be made at a site so that the areal occurrence of permafrost is adequately delineated. This is particularly important in the discontinuous zone where permafrost occurs in scattered patches or "islands" in combination with areas of thawed ground.

All information collected should be recorded on data sheets. Typical sheets of recorded information have been included. Most of the specific details required are noted; other pertinent information may be added.

TABLE I

ICE DESCRIPTIONS

A. ICE NOT VISIBLE[a]

Group Symbol	Subgroup: Description	Subgroup: Symbol		Field Identification
N	Poorly bonded or friable	Nf		Identify by visual examination. To determine presence of excess ice, use procedure under note[b] and hand magnifying lens as necessary. For soils not fully saturated, estimate degree of ice saturation: medium, low. Note presence of crystals or of ice coatings around larger particles.
	Well-bonded: No excess ice	Nb	Nbn	
	Well-bonded: Excess ice		Nbe	

[a] ***Frozen soils in the N group may, on close examination, indicate presence of ice within the voids of the material by crystalline reflections or by a sheen on fractured or trimmed surfaces. The impression received by the unaided eye, however, is that none of the frozen water occupies space in excess of the original voids in the soil. The opposite is true of frozen soils in the V group*** (see *p. 14*).

[b] ***When visual methods may be inadequate, a simple field test to aid evaluation of volume of excess ice can be made by placing some frozen soil in a small jar, allowing it to melt, and observing the quantity of supernatant water as a percentage of total volume.***

FIG A. ICE NOT VISIBLE

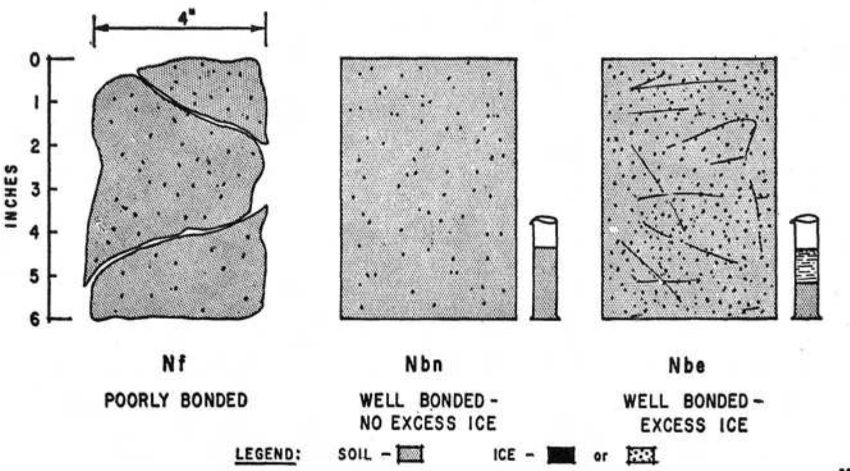

TABLE I (cont'd)

ICE DESCRIPTIONS

B. VISIBLE ICE—LESS THAN 1 INCH THICK[a]

Group Symbol	Subgroup Description	Subgroup Symbol	Field Identification
V	Individual ice crystal or inclusions	Vx	For ice phase, record the following when applicable: Location — Size Orientation — Shape Thickness — Pattern of arrangement Length Spacing Hardness, Structure, Colour } per Group C (see p. 16) Estimate volume of visible segregated ice present as percentage of total sample volume.
	Ice coatings on particles	Vc	
	Random or irregularly oriented ice formations	Vr	
	Stratified or distinctly oriented ice formations	Vs	

[a] *Frozen soils in the N group may, on close examination, indicate presence of ice within the voids of the material by crystalline reflections or by a sheen on fractured or trimmed surfaces. The impression received by the unaided eye, however, is that none of the frozen water occupies space in excess of the original voids in the soil. The opposite is true of frozen soils in the V group.*

FIG B. VISIBLE ICE LESS THAN ONE INCH THICK

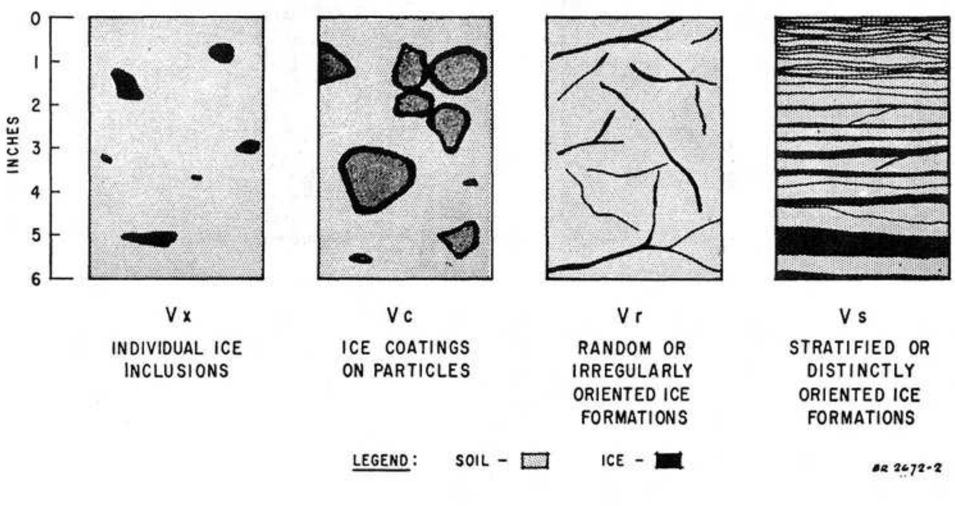

TABLE I (cont'd)

ICE DESCRIPTIONS

C. VISIBLE ICE—GREATER THAN 1 INCH THICK

Group Symbol	Subgroup Description	Subgroup Symbol	Field Identification
ICE	Ice with soil inclusions	ICE + soil type	Designate material as ICE[a] and use descriptive terms as follows, usually one item from each group, when applicable: Hardness: HARD, SOFT (of mass, not individual crystals) Structure[b]: CLEAR, CLOUDY, POROUS, CANDLED, GRANULAR, STRATIFIED Colour (Examples): COLOURLESS, GRAY, BLUE Admixtures (Examples): CONTAINS FEW THIN SILT INCLUSIONS
	Ice without soil inclusions	ICE	

[a] *Where special forms of ice such as hoarfrost can be distinguished, more explicit description should be given.*
[b] *Observer should be careful to avoid being misled by surface scratches or frost coating on the ice.*

FIG C. VISIBLE ICE GREATER THAN ONE INCH THICK

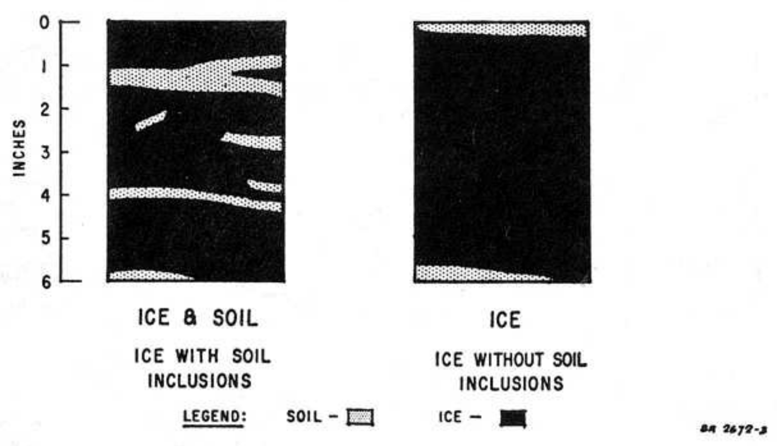

TABLE II

TERMINOLOGY

Ice Coatings on Particles are discernible layers of ice found on or below the larger soil particles in a frozen soil mass. They are sometimes associated with hoarfrost crystals, which have grown into voids produced by the freezing action.

Ice Crystal is a very small individual ice particle visible in the face of a soil mass. Crystals may be present alone or in combination with other ice formations.

Clear Ice is transparent and contains only a moderate number of air bubbles.

Cloudy Ice is relatively opaque due to entrained air bubbles or other reasons, but which is essentially sound and non-pervious.

Porous Ice contains numerous voids, usually interconnected and usually resulting from melting at air bubbles or along crystal interfaces from presence of salt or other materials in the water, or from the freezing of saturated snow. Though porous, the mass retains its structural unity.

Candled Ice is ice that has rotted or otherwise formed into long columnar crystals, very loosely bonded together.

Granular Ice is composed of coarse, more or less equidimensional, ice crystals weakly bonded together.

Ice Lenses are lenticular ice formations in soil occurring essentially parallel to each other, generally normal to the direction of heat loss and commonly in repeated layers.

Ice Segregation is the growth of ice as distinct lenses, layers, veins, and masses in soils commonly but not always, oriented normal to direction of heat loss.

Well-bonded signifies that the soil particles are strongly held together by the ice and that the frozen soil possesses relatively high resistance to chipping or breaking.

Poorly-bonded signifies that the soil particles are weakly held together by the ice and that the frozen soil consequently has poor resistance to chipping or breaking.

Friable denotes extremely weak bond between soil particles. Material is easily broken up.

Excess Ice signifies ice in excess of the fraction that would be retained as water in the soil voids upon thawing.

For a more complete list of terms generally accepted and used in current literature on Frost and Permafrost see Hennion, F. "FROST AND PERMAFROST DEFINITIONS", Highway Research Board, Bulletin 111, 1955.

APPENDIX A

SAMPLE FORMS FOR PERMAFROST FIELD RECORDS

I. EXPLORATION & TERRAIN NOTES

1. LOCATION: Thunder River, N.W.T.
   SITE: Centre Proposed Hostel—Site 4
   AIR PHOTO: A 18635–49; N 1.7, W 4.3
   NA & NR. Plan—TR-A-1
   NOTES BY: John Smith

   HOLE No. T.P. 24
   DEPTH: 22'
   ELEVATION: 28' above river water level (hand level)
   DATE: START a.m. 14/8/56
   END p.m. 17/8/56

2. METHOD OF EXPLORATION: Portable gasoline powered jackhammer.
   Pit Size—4' x 6'—3 local labourers.
   REMARKS: No difficulties, log cribbing from 14'–22'.
   Rain all day 15/8/56

3. VEGETATION COVER

   SYMBOL—SITE FEI
   AREA IF

   DESCRIPTION: At Site—irregular distribution of grass hummocks and sedges with moss covering most of surface—odd low shrub. Area—predominantly moss covered with irregular distribution of grasses and sedges.

4. RELIEF
   REGION: Lowland, flat, recent alluvium.
   SITE: 6" high grass tussocks, some mounds 4' in diameter and 1' high.

5. DRAINAGE: Poor—many puddles of scum covered water. During spring run off overflow probably runs to small creek 200' E. (which is now dry) and thence to river.

6. GENERAL
   DEPTH OF THAW—HOLE-AVERAGE 20" Max. 26" Min. 10" DATE 16/8/56
   AREA-AVERAGE 18" Max. 27" Min. 10" DATE 16/8/56
   REMARKS: Local inhabitants report wind packed snow drifts up to 5' deep cover site.

II. PERMAFROST — SUBSURFACE FEATURES

Depth, ft.	Hole Log	Depth, ft.	Soil Description	Depth, ft.	Ice Description	Soil Samples	Photo	Remarks
	Pt		Cat. #8—light to dark brown		THAWED			Photos taken on north wall of pit
2 4	Pt Pt Nbn	1.2	Peat—category #13—reddish brown to dark brown—1 branch at 3.5 ft.—4 in. in diameter	1.6	Frozen—no visible ice seg., well bonded—material breaks in slabs 12" long x 3" thick		1	
6	Pt Vs in Nbn			4.6	Hairline ice lenses, about 1" spacing in Nbn		1	
8	SM Vs	6.8	Light brown silty fine sand	6.8	H.L. hor. lenses ⅛" to ½" spacing, visible ice = 15% of total volume	2—M/C 1—G.S.	1	
10	CH Vs	8.5	Grey clay, high plasticity, random small (¼" dia) rounded pebbles	8.5	1" hor. ice lenses spaced about 8 in.—odd diagonal h.l. ice lens (2-3 in. long)	1—G.S. 2—M/C	1	
12 14	CH Nbn			10.8	No visible ice segregation, well bonded	3—M/C 1—G.S.	1	
16	ICE	14.3		14.3	Ice with clay inc.—ice soft, cloudy, milky white; clay incl.—angular, avge. 1" long, ¼" thick		1	
18				17.7	Ice soft, cloudy, milky white		1	
20	GP Vc	19.0	Gravel, poorly graded, mostly rounded stones ½"–2" in diameter	19.0	Ice coating stones up to ½" thick, average thickness about ⅛"	1—G.S.	1	
22		22.0	BOTTOM OF EXPLORATION					

Location—Thunder R., N.W.T. Site—Hostel—Site #4 Hole No.—T.P. 24	Boring—Start—14.8.56 End —17.8.56 Notes by—J. Smith	Org. Terrain—F.E.I. Topography—Flat lowland Elevation—28' above river level