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…PID DETECTION OF WATER SOURCES …COLD REGIONS

…ELECTED BIBLIOGRAPHY OF POTENTIAL TECHNIQUES

D.W. Smith, G.A. Smith, J.M. Brown,
R.L. Schraeder and L. Kosikowski

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A review of current literature on existing techniques that could be utilized in the rapid location of water sources for field camp use in permafrost regions resulted in the selection of three non-ground contact methods of electrical resistivity and two radar methods as being the most effective techniques. The search included thousands of references; 77 of these were chosen to be included in the annotated bibliography. The interest level or pertinence of each entry to the study is indicated, and keywords are provided. The keyword index contains all keywords for all entries listed in alphabetical order.

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PREFACE

This report was prepared by Dr. D.W. Smith, Environmental Engineer, G.A. Smith, Geologist, Dr. J. McCaslin Brown, Geologist, R.L. Schraeder, Geologist, and L. Kosikowski, Geologist, of R&M Consultants, Inc., Anchorage, Alaska, for the U.S. Army Cold Regions Research and Engineering Laboratory (USACRREL).

The study was funded under DA Project 4A762730AT42, Design, Construction and Operations Technology for Cold Regions; Task A3, Facilities Technology; Work Unit 009, Water Supply in Cold Regions.

Project monitor for this report was R.S. Sletten, who along with S.C. Reed and S.A. Arcone of CRREL, reviewed the technical content of the report. CRREL Editorial Reviewer, Ms. Mona McDonald, reviewed the document and contributed many valuable comments and suggestions.

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CONTENTS

I. SUMMARY

As part of a study by the U. S. Army Cold Regions Research and Engineering Laboratory (CRREL), this report is a compilation of current literature on existing techniques which could be utilized in the rapid location of water sources for field camp use in permafrost regions. Literature references are presented in the bibliography with an abstract included for each citation.

After a review of the literature cited herein, three techniques were selected as being the most feasible for the subject task. These three techniques, radiohm electrical resistivity, magnetic induction electrical resistivity and ground probing radar, are discussed in detail in this report. No absolute rating system was utilized for making the selections. However, the major techniques were chosen mainly on the basis of accuracy and reliability of results. Also considered were the field portability of instruments, the suitability of the techniques for small scale operation, and the ability of investigators to make field evaluations of the results without time consuming office processing or mathematical analysis.

Other techniques may be usable; however, their limitations were considered too great to recommend their use except in special circumstances. For instance, satellite imagery has proven useful on a regional basis for the determination of permafrost areas and it might be useful in selecting sites for field camps. But as a tool for locating water sources in a limited area, it is not a viable technique. These less suitable techniques are briefly reviewed in this report.

II. INTRODUCTION

Purpose: The purpose of this study is to evaluate existing techniques which might provide rapid detection of water sources beneath snow and/or ice in arctic regions, to provide an annotated bibliography on the subject and to recommend which of the many techniques seem to warrant further study and development. Short term field camps located in arctic regions often have major problems in developing a water supply because of the permafrost conditions which generally prevail. Previously, subsurface water and partly frozen surface water could usually be detected only by exploratory drilling in areas which would most logically contain unfrozen water. The use of detection techniques which could facilitate the selection of drill sites would greatly reduce the time and expense required to develop an adequate water supply for a field camp. In recent years many new techniques have been developed and perfected which could be utilized to that end. Some have proven useful in arctic hydrological investigations, but many have not been employed to any great extent in this type of study, though they may be adaptable to such use.

This study attempts to consolidate as much published information as possible on techniques which have been used or which could be utilized for the detection of potential water sources covered by snow and/or ice in the winter in arctic regions.

Study Approach: An attempt was made in preparing this study to collect relevant references from as many varied sources as possible.

The initial effort involved a computer search utilizing a cross-section of major data bases available in the NOAA computer research system. In conjunction with this effort, contacts were made by mail with known researchers, certain federal, state and provincial agencies, research laboratories and universities with arctic or geophysical divisions. In addition, CRREL subject indexes from 1969 - 1978 were searched. From this base the search broadened rapidly as responses were received and reference lists from collected articles were checked for related publications. The final list of relevant citations, presented in the form of annotated bibliographic references, is contained in this report. Each reference was classified as Interest Level 1, 2 or 3. This grouping was an attempt by the reviewers to show a relative degree of pertinence for each citation. Interest Level 1 is the most relevant for the purpose of this study.

III. MOST EFFECTIVE TECHNIQUES

Water sources in the Arctic occur according to the same geological and hydrological principles prevailing in temperate regions. However, the prevalent subfreezing temperatures in the Arctic restrict the amounts and locations of water in the liquid state. The distribution of permafrost (perennially frozen ground) and seasonal frost restricts the distribution and flow of groundwater and surface water. Therefore, the search for water supplies in the permafrost regions of the Arctic consists of the search for sources of groundwater or surface water which will remain unfrozen throughout the year.

Several surface geophysical techniques rapidly provide data which allow the definition of unfrozen sources of water. These techniques include:

. Radiohm Electrical Resistivity

. Wavetilt Electrical Resistivity

. Magnetic Induction Electrical Resistivity

. Ground Probing Radar

. Infrared Imagery

Radiohm Electrical Resistivity

The radiohm method utilizes radio frequencies in the VLF (15-25 kHz) and LF (300-415 kHz) bands. Vertically polarized radio waves generated by military and time standard VLF stations, and navigational aid LF transmitters are used. The VLF stations are extremely powerful and, at distances of approximately 1000 Km and greater, radiowaves reflected from the ionosphere are used.

The small hand held models EMI6 and EM32 built by Geonics Ltd. are receivers used to compare the horizontal earth tangential components of the electric and magnetic field with each other. The amplitude of this comparison allows the determination of an apparent resistivity of the subsurface materials while the phase difference between the components gives information on the resistivity gradient with depth. Operating temperature range is -40° to 50°C. The effective depth of the investigation is related to soil resistivity and frequency with lower frequencies giving greater penetration. Reading time of the instrument ranges from 10-40 seconds.

Wavetilt Electrical Resistivity

An airborne system termed E-PHASE has been developed by Barringer Research, Ltd. This unit measures the field strength of the horizontal electric component of the propagated wave which is in phase quadrature to the vertical electric component. Measurements of the quadrature horizontal electric field strength are related to the total horizontal field strength and can be used to derive a good approximation of the forward tilt of the electric vector. This forward tilt is related to ground resistivity and thus the measurement enables estimates of ground resistivity to be made down to the skin depth of penetration of the radio waves. Units using broadcast band LF and VLF frequencies simultaneously have been used. The penetration depth varies for both frequencies and in the overlap zone layering effects can be more readily evaluated. Signal penetration for the broadcast band is 10 ft. to 100 ft. and for VLF it is 50 ft. to 500 ft.

Magnetic Induction Electrical Resistivity

The magnetic induction electrical resistivity technique, also termed dipole-dipole inductive coupling, uses a self-contained instrument; that is, a signal is transmitted by one loop dipole antenna and received by the second dipole. In the case of the EM31, built by Geonics Ltd., the dipoles are horizontally coplanar and separated by a fixed distance of 3.6 m. The transmitted signal induces a primary magnetic field and also induces current flow in the ground which induces a secondary magnetic field. The received signal is the sum of the primary field and the secondary field, which has both in phase and quadrature phase components, with respect to the primary field. The resistivity of the ground is determined from the quadrature phase component of the ratio of secondary to primary fields.

The depth of exploration is determined primarily by the earth resistivity and the separation of the two dipoles and is less affected by frequency than the radiom method. For the EM31, the depth of exploration is approximately 7 to 10 m. and reading time is approximately 1 second.

The EM34 built by Geonics Ltd. uses two dipoles that can be separated by either 15 m. or 30 m. In this manner the depth of penetration will be approximately 10 m. or 25 m. respectively. It is understood that a newer version of the EM34 may allow a third spacing to provide greater penetration and that other units operating at different frequencies are being developed. Reading time of these two instruments ranges from 10 to 100 sec. The magnetic induction unit is particularly sensitive in the low resistivity range, making the unit applicable for determining thaw zones in conductive permafrost terrain.

Ground Probing Radar

Very high frequency (VHF) impulse radar has been used for probing structure and distribution of electric properties in permafrost. The radar signals are sensitive to the differences between electrical properties of frozen and thawed ground which are related to the physical state of the moisture content. These differences are primarily reflected in the dielectric polarization of the soil. The contrasting dielectrics cause sufficient changes in radar returns to allow accurate delineation of these two different conditions.

A radar system developed by Geophysical Survey Systems, Inc. (GSSI) and using separate transmit and receive antennas has been successfully tested in locating thawed areas in permafrost terrain. Two impulse duration times are available. The 2-ns impulse system can provide high resolution information from shallow depths of 3 to 5 m. The 10-ns impulse system gives less resolution to considerably greater depth. A recently developed GSSI unit which is currently being tested is compact and can be hand carried. It utilizes a 21-ns burst at a center frequency of 100 MHz.

Impulse radars require no ground contact, are usually towed on a sled and can continuously provide data which is relatively easy to interpret. Airborne impulse radar units have been used for monitoring sea-ice thickness for some time. The technique has airborne capability if the system for mapping geologic structure and electrical properties of permafrost can be adequately refined to employ it.

Infrared Imagery

High altitude thermal infrared imagery has been used to map permafrost on a regional basis and extensive mapping of sea-ice has been done with IR Scanners. Infrared techniques have the advantage of being used in an airborne mode which is very desirable in remote northern areas. The only documented use of IR Scanners for water supply studies has been in the determination of partly frozen fresh water lakes. A zone of unfrozen water produces a thermal effect at the surface which has sufficient magnitude to be measurable by airborne equipment. IR Scanning has the potential for quick efficient surveys to determine the surface effect of subsurface thermal conditions. Studies have not as yet been made to ascertain how successfully the imagery could be evaluated for the occurence of potential water sources, but it might prove usefull in making an inventory of existing or probable sources prior to the actual need.

IV. OTHER TECHNIQUES

Seismic Refraction

Seismic refraction systems have long been the most commonly used methods for permafrost investigations. The system records layers of increasing velocity. The relative comparison of velocities indicates depth to permafrost and extent of permafrost without the requirement of boreholes for velocity control as in seismic reflection studies. Refraction methods can be used to map permafrost in discontinuous zones and can detect steeply dipping subsurface boundaries. In thawed areas the zone of saturation acts as a refractor and the water table can sometimes be recognized seismically. The primary limitation of the refraction method is that it only records layers having velocities higher than those in overlying layers. The method is able to determine the depth to permafrost beneath unfrozen soils; however, one meter of seasonal frost restricts the effective use, so in many cases the method cannot be used for winter time investigations. Although a series of individually isolated spreads can be effective and the involvement of personnel and equipment is considerably less than for reflection profiles, the time and expense of field layout and data interpretation make this technique only marginally suitable for the scope of work being considered in this study.

Probe Resistivity

Contrasts in resistivity between active layers and permafrost are usually high, enabling this technique to be used to identify permafrost boundaries and thawed zones within permafrost areas. Several variations of probe placement are used, e.g., Schlumberger, and Wenner, and all have proven effective when emplaced in thawed surface soils. However, problems with probe-soil contact resistance make this method difficult to use in frozen ground. Additionally, it is much slower than the non-contact EM techniques and is less efficient than other available methods although its resolution may be far superior.

Magnetotelluric Surveys

This method utilizes the same principles as the Radiohm method but at frequencies generally from 1 Hz to 10 kHz. These frequencies are generated by telluric currents which are naturally occurring currents that are induced by distant lightning discharges. Sensitive magnetotelluric instruments detect the currents and their associated magnetic fields and provide a resistivity technique which has not been extensively used. To date the only magnetotelluric hydrology studies have been reconnaissance investigations of large basins. Modeling is required for interpretation of the collected data. The technique has been effective using a simple two-layer model consisting of electrically resistive permafrost over less resistive nonfrozen material. The base of the permafrost is readily discernible in flat or gently sloping terrain, and the technique could be utilized when drilling for sub-permafrost waters is required.

Microwave Radiometry

Remote sensing using the microwave portion of the electromagnetic spectrum has seen considerable use in monitoring environmental conditions. In related uses, microwave radiometry has been experimented with for soil moisture mapping, snow cover mapping and sea-ice thickness measurements. Subsurface microwave emissions are often screened by surface features. This limitation must be overcome by the development of more refined radiative transfer models and mathematical models for surface roughness before the technique can be effectively used.

Magnetic Surveys

Magnetic surveys have been used to a minor degree for hydrogeologic studies. However, in arctic regions where groundwater occurrence is controlled by permafrost conditions rather than by the magnetic characteristics of aquifers, magnetic surveys are not a viable technique.

Gravity Profiling

Gravimetric surveys have been successful in locating massive ice occurrences in permafrost areas where topographic characteristics indicated a possible occurrence and where borehole data were available. Subsurface conditions in most northern areas are not well known and there is very little information available for modeling and interpreting gravity data. As a result, the gravimeter as a preliminary and independent tool for use in permafrost hydrologic investigations is very limited.

Satellite Remote Sensing

ERTS-1 imagery provides an excellent tool for delineating permafrost on a regional basis, but for site specific hydrological investigations of the type envisioned in this study, it is not considered suitable.

Seismic Reflection

Seismic reflection is the primary geophysical exploratory technique of the petroleum industry. In comparison to the readily portable first-arrival-time refraction seismic devices, the somewhat more sophisticated equipment used, the borehole control required and the relative difficulty of interpreting the data put this technique outside the scale of the projects considered here.

Side-Looking Airborne Radar

Side-looking airborne radar (SLAR) has been shown capable of recording differences in soil moisture content and of differentiating fresh water lakes with only an ice cover from those frozen to the bottom and from brackish lakes. This technique would enable searchers to quickly search large areas and identify any lakes which might supply quantities of fresh water. Additionally, it appears that SLAR might be able to locate unfrozen zones beneath thin seasonal frost or possibly unfrozen areas beneath snow cover. It appears that this technique might be worth further investigation.

V. ANNOTATED BIBLIOGRAPHY

An annotated bibliography of all references located during this study is contained in an appendix. The references are organized alphabetically by author and each contains a summary of the cited work. The interest level shown for each reference ranges from 1 to 3, with Level 1 indicating the highest relative interest, or degree of pertinence, for this study. The first part of the two part number next to the reference is a consecutive numerical listing of the 77 references. The second portion of the number is the interest level for that reference. This number is the index reference number used in the Keyword Index to identify each reference.

VI. KEYWORD INDEX

The alphabetical keyword index which follows the bibliography includes, for each listing, the index number of the reference and the keywords pertaining to the reference. The two-part index number consists of a consecutive numerical listing for the 77 references and the interest level, which is indicated by the last figure. The references are repeated alphabetically for each of the keywords associated with them.

The keywords have been selected by the authors or, in some cases, were taken from keyword listings which occur with the publications.

Index Number	Keywords
24-3	Acoustic measurement, Oceanographic equipment, Sea ice, Sound wave
31-1	Aerial surveys, Electrical resistivity, Geological surveys, Soil surveys
59-3	Aerial survey, Allagash, Maine, Electrical resistivity, Geophysics, Structural geology, Subsurface investigations
62-3	Aerial surveys, Allagash, Maine, Electrical resistivity, Geological surveys, Soil surveys, Subsurface investigations.
38-2	Airborne Infrared, Permafrost, Massive ice
10-1	Airborne resistivity, Permafrost
17-1	Airborne resistivity, E-phase, Gravel investigation
30-1	Airborne resistivity, Ground resisivity, Permafrost
34-1	Airborne survey, Impulse radar, Ice
43-1	Air photos, Imaging radar, Permafrost, Soil moisture
61-2	Alaska, Ice, Images, Lakes, Permafrost, Thaw lakes, Arctic coastal plain
59-3	Alagash, Maine, Electrical resistivity, Geophysics, Structural geology, Subsurface investigations, Aerial survey
62-3	Alagash, Maine, Electrical resistivity, Geological surveys, Soil surveys, Subsurface investigations, Aerial surveys
55-1	Aquifer, Groundwater, Surface resistivity
20-1	Aquifer location, Radiowave, Electrical resistivity, Groundwater.
74-1	Aquifer location, Gravity anomalies, Groundwater determination, Hydogeology
61-2	Arctic coastal plain, Alaska, Ice, Images, Lakes, Permafrost, Thaw Lakes
27-3	Bedrock detection, Permafrost, Seismic studies
18-1	Computer assistance, EM Sounding, Permafrost
06-1	Copper River Basin, Magnetic induction, LF radio wave, VLF radio wave, Test site, Fox ice tunnel
64-1	Dielectric properties, Electromagnetic survey, Permafrost delineation
15-2	Dielectric properties, Resistivity survey, Seawater resistivity, Permafrost
58-2	EM sounding, Massive ice, Radar impulse, Permafrost detection
18-1	EM sounding, Permafrost, Computer assistance
54-1	EM sounding, Permafrost, Magnetotellurics
65-2	EM sounding, Permafrost, Resistivity
17-1	E-Phase, Airborne resistivity, Gravel investigation
66-1	Echo sounding, Electrical properties of ice and water, Radio waves
52-1	Echo sounding, Ice thickness, Remote sensing
07-1	Electrical parameters, Overburden depth, Radio waves
66-1	Electrical properties of ice and water, Echo sounding, Radio waves
35-1	Electrical prospecting, Permafrost thickness, Geoelectricity, Electrical resistivity
20-1	Electrical resistivity, Groundwater, Aquifer location, Radiowave

Index Number	Keywords
22-2	Electrical resistivity, Permafrost, Seismic refraction
29-1	Electrical resistivity, Groundwater, Permafrost, Seismic refraction, Seismic reflection
01-1	Electrical resistivity, Permafrost, Seismic refraction, Water supply
31-1	Electrical resistivity, Geological surveys, Soil surveys, Aerial surveys
35-1	Electrical resistivity, Permafrost thickness, Geoelectricity, Electrical prospecting
59-3	Electrical resistivity, Geophysical, Structural geology, Subsurface investigations, Aerial survey, Allagash, Maine
62-3	Electrical resistivity, Geological surveys, Soil surveys, Subsurface investigation, Aerial surveys, Allagash, Maine
64-1	Electromagnetic survey, Dielectric properties, Permafrost delineation
76-1	Electromagnetic survey, Groundwater detection, Hydrogeology, Magnetotelluri survey, Resistivity survey
42-2	Electromagnetic survey, Sea ice thickness, Remote sensing
26-1	Electromagnetic testing, Inductive coupling, LF radiohm, Permafrost detection
05-1	Freshwater ice thickness, Radar sensing, Remote sensing
23-1	Frozen ground resistivity, Resistivity values, Seismic velocities
06-1	Fox ice tunnel, Copper River Basin, Magnetic Induction, LF radiowave, VLF radiowave, Test sites
35-1	Geoelectricity, Permafrost thickness, Electrical prospecting, Electrical resistivity
31-1	Geological surveys, Soil survey, Aerial surveys, Electrical resistivity
62-3	Geological surveys, Soil survey, Aerial surveys, Allagash, Maine, Electrical resistivity
21-2	Geophysical methods, Permafrost mapping, Groundwater prediction
57-1	Geophysical techniques, Permafrost
59-3	Geophysics, Structural geology, Subsurface investigations, Aerial surveys, Allagash, Maine, Electrical resistivity
51-1	Glacial deposits, Permafrost thickness, Seismic refraction, Seismic velocity
45-2	Glacier, Radio echo
12-2	Glacier snow, Sea ice, Radar imagery
17-1	Gravel investigation, Airborne resistivity, E-PHASE
74-1	Gravity anomalies, Aquifer location, Groundwater determination, Hydrogeology
32-1	Gravity profiling, Groundwater detection, Permafrost delineation
03-1	Ground probing radar, Permafrost
30-1	Ground resistivity, Airborne resistivity, Permafrost
45-2	Ground temperature, Permafrost, Groundwater
55-1	Groundwater, Aquifer, Surface resistivity
20-1	Groundwater, Aquifer location, Radiowave, Electrical resistivity

Index Number	Keywords
29-1	Groundwater, Electrical resistivity, Permafrost, Seismic refraction, Seismic reflection
45-2	Groundwater, Ground temperature, Permafrost
73-3	Groundwater, Icings, Permafrost, Water resources
47-2	Groundwater, Infrared, Hydrogeology
25-3	Groundwater, Infrared imagery, Snow and ice melt
68-1	Groundwater, Pollution, Resistivity contrasts
72-3	Groundwater, Subsurface geology, Permafrost, Landforms
76-1	Groundwater detection, Electromagnetic survey, Hydrogeology, Magnetotelluric survey, Resistivity survey
32-1	Groundwater detection, Gravity profiling, Permafrost delineation
74-1	Groundwater determination, Aquifer location, Gravity anomalies, Hydrogeology
75-1	Groundwater determination, Hydrogeologic mapping, Seismic reflection, Seismic refraction
77-1	Groundwater determination, Hydrogeology, Magnetic surveys
09-2	Groundwater in permafrost, Seismic refraction, Resistivity survey
21-2	Groundwater prediction, Permafrost mapping, Geophysical methods
36-2	Heat transfer
68-2	Holographic survey, Satellite, Permafrost
75-1	Hydrogeologic mapping, Groundwater determination, Seismic reflection, Seismic refraction
74-1	Hydrogeology, Aquifer location, Gravity anomalies, Groundwater determination
76-1	Hydrogeology, Electromagnetic survey, Groundwater detection, Magnetotelluric survey, Resistivity survey
77-1	Hydrogeology, Groundwater determination, Magnetic surveys
47-2	Hydrogeology, Infrared, Groundwater
48-1	Infrared imagery, Permafrost, Sea ice, Water supply
36-2	Infrared, Sea ice thickness, Heat transfer
34-1	Ice, Airborne survey, Impulse radar
61-2	Ice, Images, Lakes, Permafrost, Thaw lakes, Arctic coastal plain, Alaska
63-1	Ice, Images, Lakes, Side-looking radar, Thickness
14-2	Ice thickness, Remote sensing, Water content, Infrared imagery
14-2	Infrared imagery, Remote sensing, Ice thickness, Water content
25-3	Infrared imagery, Groundwater, Snow and ice melt
26-1	Inductive coupling, Electromagnetic testing, LF radiohm, Permafrost detection
39-1	Ice thickness, Remote sensing, Lake ice
40-3	Infrared imagery, Springs
43-1	Imaging radar, Air photos, Permafrost, Soil moisture
61-2	Images, Lakes, Permafrost, Thaw lakes, Arctic coastal plain, Alaska
34-1	Impulse radar, Ice, Airborne survey
50-2	Ice thickness, Remote sensing, Permafrost, Terrain analysis
52-1	Ice thickness, Echo sounding, Remote sensing

Index Number	Keywords
15-2	Permafrost, Resistivity survey, Seawater resistivity, Dielectric properties
49-3	Permafrost, Seismic detonation
67-2	Permafrost, Seismic refraction, Seismic reflection
33-1	Permafrost, Seismic refraction, Seismic velocities
37-2	Permafrost, Seismic velocities
53-2	Permafrost, Seismic velocity, Seismic refraction, Seismic reflection
72-3	Permafrost, Subsurface geology, Landforms, Groundwater
61-2	Permafrost, Thaw lakes, Arctic coastal plain, Alaska, Ice, Images, Lakes
64-1	Permafrost, Delineation, Dielectric properties, Electromagnetic survey
32-1	Permafrost delineation, Gravity profiling, Groundwater detection
26-1	Permafrost detection, Electromagnetic testing, Inductive coupling, LF radiohm
58-2	Permafrost detection, Massive ice, Radar impulse, EM sounding
46-1	Permafrost detection, Permafrost structure, Lake ice, Radar
02-2	Permafrost distribution, Satellite, Terrain identification
21-2	Permafrost mapping, Groundwater prediction, Geophysical methods
46-1	Permafrost structure, Lake ice, Radar, Permafrost detection
04-1	Permafrost studies, Radar echoes
08-1	Permafrost studies, Resistivity, Seismic refraction
35-1	Permafrost thickness, Geoelectricity, Electrical prospecting, Electrical resistivity
51-1	Permafrost thickness, Glacial deposits, Seismic refraction, Seismic velocity
68-1	Pollution, Groundwater, Resistivity contrasts
46-1	Radar, Permafrost detection, Permafrost structure, Lake ice
04-1	Radar echoes, Permafrost structure
12-2	Radar imagery, Sea ice, Glacier snow
58-2	Radar impulse, Massive ice, EM sounding, Permafrost detection
05-1	Radar sensing, Remote sensing, Freshwater ice thickness
44-2	Radio echo, Glaciers
16-3	Radiometry, Microwave radiation, Remote sensing
07-1	Radio wave, Electrical parameters, Overburden depth
20-1	Radio wave, Electrical resistivity, Groundwater, Aquifer location
11-3	Radio wave, echo sounding, Electrical properties of ice and water
05-1	Remote sensing, Freshwater ice thickness, Radar sensing
14-2	Remote sensing, Ice thickness, Water content, Infrared imagery
16-3	Remote sensing, Microwave radiation, Radiometry
39-1	Remote sensing, Ice thickness, Lake ice
41-1	Remote sensing, Temperature difference, Thermal imagery
42-2	Remote sensing, Sea ice thickness, electromagnetic survey
50-2	Remote sensing, Ice thickness, Permafrost, Terrain analysis
52-1	Remote sensing, Echo sounding, Ice thickness

Index Number	Keywords
71-3	Remote sensing, Road-icing, Ice detection
65-2	Resistivity, EM sounding, Permafrost
08-1	Resistivity, Permafrost studies, Seismic refraction
68-1	Resistivity contrasts, Groundwater, Pollution
56-1	Resistivity (DC), Permafrost
09-2	Resistivity survey, Seismic refraction, Groundwater in permafrost
15-2	Resistivity survey, Seawater resistivity, Dielectric properties, Permafrost
76-1	Resistivity survey, Electromagnetic survey, Groundwater detection, Hydrogeology, Magnetotelluric survey
23-1	Resistivity values, Frozen ground resistivity, Seismic velocities
71-3	Road icing, Remote sensing, Ice detection
02-2	Satellite, Terrain identification, Permafrost distribution
70-2	Satellite, Holographic survey, Permafrost
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13-2	Sea ice, VLF radio waves
24-3	Sea ice, Acoustic measurement, Oceanographic equipment, Sound waves
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42-2	Sea ice thickness, Remote sensing, Electromagnetic survey
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67-2	Seismic refraction, Seismic reflection, Permafrost
75-1	Seismic refraction, Groundwater determination, Hydrogeologic mapping, Seismic reflection
27-3	Seismic studies, Bedrock detection, Permafrost

Index Number	Keywords
23-1	Seismic velocities, Frozen ground resistivity, Resistivity values
33-1	Seismic velocities, Permafrost, Seismic refraction
37-2	Seismic velocities, Permafrost
51-1	Seismic velocity, Glacial deposits, Permafrost thickness, Seismic refraction
53-2	Seismic velocity, Seismic refraction, Seismic reflection, Permafrost
62-1	Side-looking radar, Thickness, Ice, Images, Lakes
25-3	Snow and ice melt, Groundwater infrared imagery
43-1	Soil moisture, Air photos, Imaging radar, Permafrost
31-1	Soil surveys, Aerial surveys, Electrical resistivity, Geological surveys
62-3	Soil surveys, Subsurface investigations, Aerial surveys, Allagash, Maine, Electrical resistivity, Geological surveys
24-3	Sound waves, Acoustic measurements, Oceanographic equipment, Sea ice
40-3	Springs, Infrared imagery
72-3	Subsurface geology, Permafrost, Landforms, Groundwater
59-3	Subsurface investigations, Aerial surveys, Allagash, Maine, Electrical resistivity, Geophysics, Structural geology
62-3	Subsurface investigations, Aerial surveys, Allagash, Maine, Electrical resistivity, Geological surveys, Soil surveys
55-1	Surface resistivity, Aquifer, Groundwater
41-1	Temperature difference, Thermal imagery, Remote sensing
50-2	Terrain analysis, Remote sensing, Ice thickness, Permafrost
02-2	Terrain identification, Satellite, Permafrost
06-1	Test sites, Fox ice tunnel, Copper River Basin, Magnetic induction, LF radiowave, VLF radiowave
41-1	Thermal imagery, Temperature difference, Remote sensing
61-2	Thaw lakes, Arctic coastal plain, Alaska, Ice, Images, Lakes, Permafrost
63-1	Thickness, Ice, Images, Lakes, Side-looking radar
13-2	VLF radio waves, Sea ice
06-1	VLF radiowave, Test sites, Fox ice tunnel, Copper River Basin, Magnetic induction, LF radiowave
14-2	Water content, Remote sensing, Ice thickness, Infrared imagery
73-3	Water resources, Groundwater, Icings, Permafrost
01-1	Water supply, Electrical resistivity, Permafrost, Seismic refraction
48-1	Water supply, Infrared imagery, Permafrost, Sea ice

APPENDIX

Rapid Detection of Water Sources in Cold Regions

Selected Bibliography of Potential Techniques

REFERENCE 01-1

Keywords

Seismic refraction, Water supply, Permafrost, Electrical resistivity.

Technique	Interest Level
Seismic refraction, Electrical resistivity	1

Author

Ackerman, H., 1976, Geophysical prospecting for groundwater in Alaska: U.S. Geol. Survey, Earthquake Information Bulletin, vol. 8, No. 2, p. 18-20.

Description

This is a brief article which outlines the use of seismic refraction and electrical resistivity to locate subsurface zones of lower seismic velocity and electrical resistivity. These zones are likely water reservoirs.

Availability

U.S. Geological Survey, Arlington, VA 22202

REFERENCE 02-2

Keywords

Terrain identification, Permafrost distribution, Satellite

Technique	Interest Level
Satellite, photo interpretation	2

Author

Anderson, D. M., 1972, Delineation of permafrost boundaries and hydrologic relationships: U.S. Army Cold Regions Research and Engineering Laboratory, ERTS-1 Symposium Proceedings, Greenbelt, Maryland 1972.

Description

The analysis of the Koyukuk-Kobuk River area from the ERTS-1 MSS color composite was performed by a team consisting of geographer, geologist, soils scientist, and hydrologist. Information was obtained concerning vegetation density and species composition, surficial geology units and five categories of permafrost. The latter included bedrock and colluvium, scattered taliks, dissected alluvial deposits, active floodplains, abandoned floodplains, and alluvial-colluvial deposits; and the characteristics of each.

Availability

CRREL, Hanover, NH

REFERENCE 03-1

Keywords
Permafrost, Ground probing radar

Technique
Ground probing radar (GPR), Time domain reflectometry

Interest Level
1

Author
Annan, A.P., and Davis, J.L., 1977, Use of radar and time domain reflectometry in permafrost studies: in Proceedings of a Symposium on Permafrost Geophysics, Scott, W.J. and Brown, R.J.E. (eds.), National Research Council Canada, Ottawa, p. 43-59.

Description
The radar technique is capable of providing high resolution information about the sub-surface electrical environment. Lateral resolution of tens of centimeters is possible. Vertical resolution of the same order is possible if material electrical properties are known from independent measurements (ie. wide angle reflection and refraction (WARR) sounding, time-domain reflectometry (TDR) measurements, drill control). The technique is, therefore, of great value in mapping continuity of lithology from borehole to borehole.

The main limitation of the radar method is the relatively shallow penetration depth. For most applications, information to depths of 5 to 10 m is required. In ice, water and coarse grained soils there is no difficulty in probing to these depths and greater. In silts and clays, however, penetration depths were less than 5 m with the equipment used for our experiments. Increased transmitter power and receiver dynamic range might alleviate this problem.

Availability
National Research Council Canada, Ottawa, Ontario, Canada

REFERENCE 04-1

Keywords

Radar echoes, Permafrost structure

Technique	Interest Level
Impulse radar	1

Author

Annan, A.P.; Davis, J.L. and Scott, W.J., 1975, Impulse radar profiling in permafrost, Research Geophysics and Geochemistry Division, Geological Survey of Canada, Paper 75-1C, p. 343-367.

Description

The Geological Survey of Canada investigated the use of VHF impulse radar to map geological structure and electrical properties of permafrost in situ. The test area was in the vicinity of Tuktoyaktuk, Northwest Territories. The report discusses the preliminary results of the trial. Although the results were hampered by an opaque clay till overlying much of the region, it was found that the impulse radar method can be used to delineate subsurface structure. The mean dielectric constant in the massive ground ice at the involuted hill site was 2.6 to 2.7 which lowers the density value normally assumed for ground ice. Therefore, it was found that radar impulse alone is not feasible in predicting ice content from the dielectric constant alone. In this example, the percentage of trapped air in pure ice caused a decrease in density values.

Availability

Resource Geophysics and Geochemistry Division, Geological Survey of Canada, 601 Booth Street, Ottawa, Canada.

REFERENCE 05-1

Keywords

Freshwater ice thickness, Radar sensing, remote sensing

Technique	Interest Level
Impulse radar	1

Author

Annan, A.P., and Davis, J.L., 1977, Impulse radar applied to ice thickness measurements and freshwater bathymetry report of activities: Part B; Geological Survey of Canada, Paper 77-1B.

Description

Impulse radar proved to be a quick, reliable technique for measuring freshwater ice thickness at shallow water depths. A 360 m ice bridge was traversed in about 3 minutes and the data were immediately available. It was found that differing frequency impulse duration will yield different types of information. For example, the 2 ns system data give high resolution information about ice thickness, whereas, the 10 ns system data yield information about deeper structure at the expense of resolution. The data were confirmed by subsequent drilling operations. Further research is necessary to suggest that radar can adequately detect and delineate frazil ice.

Availability

Geological Survey of Canada, Ottawa, Ontario, Canada

REFERENCE 06-1

Keywords

Test sites, Fox ice tunnel, Copper River Basin, Magnetic induction, LF radiowave, VLF radiowave.

Technique	Interest Level
Magnetic induction, surface impedance	1

Author

Arcone, S.A., Sellmann, P.V., and Delaney, A.J., 1977, Shallow electromagnetic geophysical investigations of permafrost, CRREL unpublished document, 6 p.

Description

The objective of the study was to evaluate the combined use of the surface impedance resistivity technique at LF (200-400 kHz) and at VLF (10-30 kHz), and the magnetic induction resistivity technique at a close coil spacing (3.7 m) for qualitative and quantitative studies of permafrost distribution and changes in permafrost properties. Three study areas were selected in Alaska's discontinuous permafrost zone. One was located in the Copper River Basin and two were near Fairbanks.

Despite the influence of the active layer, strong resistivity contrasts within permafrost were seen to exist at LF but not at VLF in the Goldstream Valley study near Fairbanks. Considering the skin depth values for LF in permafrost (e.g. 46 m at 356 kHz in 3000 ohm-m material), this method would be best suited for high resistivity, discontinuous permafrost zone studies performed before seasonal thaw sets in. The information gained from all three systems allowed a good estimate of the permafrost thickness at the Goldstream Valley site.

Both the LF and magnetic induction techniques had sufficient sensitivity to detect the thaw zones in all study areas, even in the low resistivity, clay-rich sediments of the Copper River Basin where resistivity contrasts between thawed and frozen states are not large. Future studies for these techniques might be permafrost detection in alluvium, where less uniformity of material type exists and where resistivity levels may be much higher for the coarser grained materials, but again with small contrasts between frozen and thawed states.

Availability

CRREL, Hanover, NH

REFERENCE 07-1

Keywords
Radio wave, Overburden depth, Electrical parameters

Technique | Interest Level
Radio wave propagation | 1

Author
Bahar, E., 1971, Radiowave propogation over a non-uniform, overburden: In J.R. Wait (ed.) Electromagnetic Probing in Geophysics, Golem Press.

Description
The article investigates the theory of using radio wave measurements to explore the undulations of the overburden depth and electrical parameters. Both the surface wave fluctuations and the directivity of the scattered radiation field could reveal the information required about the nonuniform overburden parameters. A salient feature of propagation over nonparallel stratified media is that the surface impedance is dependent upon the direction of propagation. This feature could be exploited for the purpose of these investigations.

When the substrate is the water table, for instance, the radio wave measurements, together with certain boundary conditions, could be used to map the underground water resources.

For the radio waves to be sensitive to fluctuation in overburden depth, we must use the deeper penetrating low and very low frequency radio waves. If, on the other hand, we wish to use the surface wave measurements to map the conductivity of the overburden, high frequency radio waves must be used.

The analysis presented in this chapter may be applied to three-dimensional problems provided that the variations of the depth of the electrical parameters of the overburden transverse to the propagation path are small compared to those along the propagation path.

It is suggested that a series of laboratory model studies be conducted in conjunction with radio wave measurements from existing very low frequency transmitters to assess critically the economic feasibility of this radio wave method for geophysical prospecting.

Availability
Golem Press, Boulder, Colorado

REFERENCE 08-1

Keywords
Permafrost studies, Seismic refraction, Resistivity

Technique | Interest Level
Seismic refraction, Resistivity | 1

Author
Barnes, D.F., 1973, Geophysical methods for delineating permafrost: in Permafrost, Second International Conference, Nat'l Acad. Sci., Wash., D.C.

Description
Physical properties that probably change most when interstitial water in rocks and soils freezes are the elastic moduli and the electrical conductivity. Therefore, seismic and electrical methods are believed to be the most useful geophysical methods for permafrost studies.

The seismic refraction method has been used for most permafrost investigations. The fundamental limitation of the method is that it only records layers having velocities higher than those in the overlying layers. Refraction methods thus provide a good method of mapping the extent of a permafrost layer and the depth to its upper surface. Refraction methods have also proved useful for detecting high-velocity rocks beneath permafrost.

Resistivity measurements on the ground surface are capable of determining both the horizontal and vertical extent of buried, high-resistivity bodies, such as permafrost. The Wenner procedure has been quite successful for indicating discontinuities in permafrost occurrence and in thickness of overburden. In some areas, changes in rock type or permafrost depth cause apparent resistivity changes that are as large as the changes caused by the presence or absence of permafrost in other areas, but an experienced observer can usually identify the cause of the resistivity changes correctly.

Availability
National Academy of Sciences, Washington, D.C.

REFERENCE 09-2

Keywords

Resistivity survey, Seismic refraction, Groundwater in permafrost

Technique	Interest Level
Seismic refraction and electrical resistivity	2

Author

Barnes, D.F.; MacCarthy, G.R., 1964, Preliminary report on tests of application of geophysical methods to arctic groundwater problems: U.S.G.S. Open File Report.

Description

Geophysical surveys were made during the summer and fall of 1952 in the Tanana Valley to study their application to arctic groundwater problems. Both survey methods defined the horizontal extent of the frozen ground and both were capable of determining the depth to the top of the permafrost but neither regularly yielded reliable results on the material beneath the permafrost. Additional theoretical investigations are desired. One is a theoretical examination of the attenuation of longitudinal waves traveling through a thin layer. The other is the development of theoretical multilayer-resistivity interpretation of problems in which the second layer has a very high resistivity. Further field work is also recommended. Barns feels that "It is doubtful at this time whether geophysical techniques are sufficiently developed to be valuable for use in prospecting for groundwater in areas of thick permafrost." and that a seismograph may be useful in areas where permafrost is thin and sporadic for groundwater and engineering applications.

Availability

U.S. Geological Survey, Arlington, VA 22202

REFERENCE 10-1

Keywords
Permafrost, Airborne resistivity

Technique | Interest Level
Airborne (E-PHASE) resistivity | 1

Author
Barringer, A.R., and McNeill, J.D., 1971, E-PHASE™--A new remote sensing technique for resistivity mapping. "E-PHASE" is a registered trademark of Barringer Research, Ltd.

Description
An airborne system termed E-PHASE has been developed to produce resistivity maps which utilize radio frequency fields transmitted by government owned VLF stations and commercial broadcast stations. Measurements of the quadrature horizontal electric field strength are related to the total horizontal field strength and can be used to derive a good approximation of the forward tilt of the electric vector. This forward tilt is related to ground resistivity and, thus, the measurement enables estimates of ground resistivity to be made down to the skin depth of the penetration of the radiowaves. Skin depth can be defined as the depth below the earth's surface penetrated by a particular radiowave at a particular point. It is dependent on the frequency of the radiowave and on the resistivity of the soils at that point. The use of two frequencies enables layering effects to be studied and shows considerable potential for the mapping of permafrost distribution and the location of gravel deposits.

Availability
Barringer Research, Ltd., Rexdale, Ontario, Canada

REFERENCE 11-3

Keywords
Sea ice thickness, Radiowave

Technique | Interest Level
Radio ground wave propagation | 3

Author
Biggs, A. W., 1970, Ground wave propagation over arctic sea ice: Kansas University Center for Research, Lawrence Remote Sensing Lab, White Oak, MD, Naval Oceanographic Office, Washington D.C., 29 p.

Description
Mixed path ground wave propagation is used to determine sea ice-sea water boundaries for layered or homogenous sea ice and sea water. Phase and amplitude variations provide the necessary data to determine boundary change. The variation is most sensitive when close to the boundary which increases the mapping value of the technique. Stratified media may be readily discerned if the upper layers have a lower refractive index than the lower layers. By varying the frequency of wave propagation, thickness of layers, homogeneity, and surface roughness may be determined.

Availability
Lawrence Remote Sensing Lab, Kansas University

REFERENCE 12-2

Keywords

Radar imagery, Sea ice, Glacier snow

Technique — Interest Level

Radio wave reflection — 2

Author

Biggs, A. W., 1970, Volume scattering from sea ice and glacier snow: Kansas University Center for Research, Lawrence Remote Sensing Lab; Naval Ordinance Lab, White Oak, MD, Naval Oceanographic Office, Washington D.C. 40688, 46 p.

Description

Glacier snow and sea ice are described by dielectric properties and relaxation spectra of water at microwave frequencies. The VLF spectrum is included to illustrate analogous relaxation for ice. Scattering models are brine pockets for sea ice and ice spheroids in snow fields; radar backscatter measurements of sea ice and SLAR images of snow fields are interpreted with the help of these models. Simulation of sea ice in an acoustic tank demonstrates volume and surface scattering with good qualitative results. The dielectric relaxation phenomena in water at microwave frequencies are also interpreted as a mechanism for anomalous behavior.

Availability

Naval Oceanographic Office, Washington, D.C.

REFERENCE 13-2

Keywords

VLF radio waves, Sea ice

Technique — Interest Level

Very low frequency groundwave propagation — 2

Author

Biggs, A.W., 1968, Geophysical exploration in polar areas with very low frequency phase variations: IEEE Trans. AP-16: 364-365.

Description

Geophysical exploration in polar areas is described by phase measuring variations known as the "Recovery Effect" for very low frequency ground wave propagation from homogeneous and stratified ice to sea water. "Recovery effect" phase variations are unique to mixed paths and do not occur in stratified media. The phase variations are stronger across boundaries separating homogeneous media than across boundaries separating stratified media.

Availability

Kansas University Center for Research, Lawrence Remote Sensing Lab

REFERENCE 14-2

Keywords

Remote sensing, Ice thickness, Water content, Infrared imagery

Technique	Interest Level
Remote sensing techniques within EM Range visible to microwave with emphasis on infrared.	2

Author

Brown, R.J., 1972, Arctic environmental effects on remote sensing: Defense Research Establishment, Ottawa, Remote Sensing Section, Earth Sciences Division, Ottawa, Canada.

Description

This report is a review of the effects of the Arctic environment on remote sensing within the spectral range extending from the visible to the microwave regions of the electromagnetic spectrum with emphasis upon the infrared. Besides atmospheric effects, target characteristics which are important in a remote sensing application are discussed and values of some of the more important physical quantities are presented. The report concludes with a list of recommendations and conclusions which isolate areas where further research on environmental effects on remote sensing is required. Microwave radiometry is the most useful tool in determination of liquid water content and sea ice thickness whereas infrared imagery is the most useful in distinguishing between types of ice present.

Availability

Defense Research Establishment, Remote Sensing Section, Earth Sciences Division, Ottawa, Ontario, Canada.

REFERENCE 15-2

Keywords

Resistivity survey, Seawater resistivity, Dielectric properties, Permafrost

Technique	Interest Level
Resistivity surveys, Bore holes	2

Author

Burns, R.F. and Hamilton, J.M., 1974, Some geophysical and hydrological aspects of permafrost in the Cornwallis Island area, N.W.T.: National Research Council Canada, Technical Memo 113, p. 80-91. CRREL Bibliography Item 30-812.

Description

The introduction and formation of permafrost in the area of Cornwallis Island was determined using the combined data from bore holes and resistivity surveys. The evidence gathered at several site locations suggests that seawater has filled the pore spaces of rocks in areas of recent emergence to the exclusion of meteoric waters. The seawater was frozen in the intertidal zone and became impermeable.

Availability

CRREL Hanover, NH

REFERENCE 16-3

Keywords
Microwave radiation, Remote sensing, Radiometry

Technique
Microwave radiometry

Interest Level
3

Author
Carver, K.R., 1973, Remote sensing using microwave radiometry: Region 3 Conference, Louisville, KY, Paper H-7, 6 p.

Description
A tutorial review of microwave radiometric remote sensing is presented, with emphasis on the fundamental principles of radiometry. Basic techniques of instrumentation are discussed, along with a summary of the environmental monitoring capabilities of microwave remote sensors.

Availability
Physical Sciences Laboratory, New Mexico State University, Los Cruces, NM.

REFERENCE 17-1

Keywords
Airborne resistivity, E-PHASE, Gravel investigation

Technique
Airborne resistivity

Interest Level
1

Author
Culley, R.W., 1974, Evaluation of an airborne resistivity measurement system (E-PHASE) for gravel locations: Saskatchewan Department of Highways, Technical Report 21, p. 141.

Description
An airborne resistivity method (E-PHASE) was chosen as the most promising means of investigating for buried gravel sources. The frequencies monitored simultaneously were standard broadcast band, low frequency air navigation band, and very low frequency communication band. The airborne data are computer analyzed to produce contour plots of apparent resistivity. From these plots, resistivity anomalies are selected for detailed ground checking.

Two general areas were surveyed, one where granular soils were suspected to exist between till sheets and the other in remote heavily-treed terrain. An excellent source was found in the first area; several anomalies look promising in the second area, but difficult access has hindered ground checking.

The study did not use this method for groundwater searches directly. The technique described has been used by others for that purpose.

Availability
Saskatchewan Department of Highways, Regina, Saskatchewan, Canada.

REFERENCE 18-1

Keywords
E-M sounding, Permafrost, Computer assistance

Technique
E-M Sounding

Interest Level
1

Author
Danials, J. J., Keller, G. V., and Jacobson, J.J., 1976, Computer-assisted interpretation of electromagnetic soundings over a permafrost section: Geophysics, Volume 41, No. 4, p. 752-765.

Description
In 2-loop EM sounding, the electromagnetic coupling between 2 vertical-axis loops of wire is measured as a function of frequency, for frequencies ranging from 20 Hz to 20 kHz. If the electrical structure of the earth beneath the loops is stratified, these data may then be interpreted in terms of a sequence of layer resistivities and thicknesses. This interpretation is accomplished by computing a series of curves for various resistivity profiles and comparing them with the field data to determine which matches best. Calculation of the theoretical models is carried out by applying a linear filter to solve the appropriate integral expressions. Interpretation is aided by using interactive non-linear, least-square algorithms iteratively to adjust the model parameters. The procedure was used to interpret 2-loop induction sounding, made along the Arctic Slope of Alaska during 1969 to determine permafrost thickness and character. The results indicate the 2-loop induction sounding is an effective method for mapping permafrost characteristics.

Availability
Geophysics, Tulsa, Oklahoma

REFERENCE 19-1

Keywords
Subsurface investigations, Copper River Basin Test Site, Fox ice tunnel, Magnetic induction

Technique	Interest Level
Magnetic induction (EM-31)	1

Author
Delaney, A.J., Arcone, S.A., and Sellmann, P.V., 1977, A magnetic induction technique for shallow subsurface arctic exploration, CRREL unpublished memorandum, 12 p.

Description
In some geological settings in the arctic, the magnetic induction technique has been found to be an effective way of rapidly ascertaining anomalous subsurface conditions to about 6 meters depth where high ice content or thaw zones may be the variables in otherwise fairly uniform geologic settings. The magnetic induction system avoids many shortcomings of other systems because antennas (loops) are used instead of electrodes and the system carries its own transmitter.

A non-contact technique for measuring earth electrical resistivity recently developed by Geonics, Ltd. was tested in areas of discontinuous permafrost near Fairbanks and Gulkana, Alaska. The main objective of the study was to obtain resistivity profiles in areas of massive ground ice at the two well documented test sites.

Availability
CRREL, Hanover, NH

REFERENCE 20-1

Keywords
Electrical resistivity, Groundwater, Aquifer location, Radiowave

Technique	Interest Level
Radiowave resistivity (EM-16R)	1

Author
Delaney, A., Gaskin, D., Sellmann, P.V., and Hoekstra, P., 1974, New radiowave resistivity techniques for locating groundwater supplies, CRREL Technical Note, 6 p.

Description
In this study three stages of exploration were used to find a good location for a groundwater supply for the Town of Plainfield, NH.

First, the entire area (8 acres) was surveyed by the radiowave method and measurements were made at 72 stations. This effort required approximately 3 hours of work by a 2-man crew. From the resistivity contour map a highly promising location for a well adjacent to the brook was identified.

Secondly, conventional resistivity soundings were made along two lines. From the measurement on one line the thickness and location of the resistivity layer was obtained. The measurement on the second line really was only used to illustrate differences. This effort took about 1 hour.

Thirdly, the digging of two test pits with a backhoe verified that the resistive material was indeed gravel.

The cost of using geophysical techniques (not including transportation to site) was less than placing one to three drill sample holes depending on the technique used. A previous unsuccessful test well is an example of the cost of drilling at will.

Availability
CRREL, Hanover, NH

REFERENCE 21-2

Keywords
Permafrost mapping, Geophysical methods, Groundwater prediction

Technique | Interest Level
Traditional and geophysical | 2

Author
Ferrians, O. J.; Hobson, G. D., 1973, Surveying and predicting permafrost conditions: Permafrost 2nd International Conference, N. American Contribution, Nat'l. Acad. of Sci., Washington, D.C.

Description
This report is a summary of recent developments in the area of permafrost detection in Canada and Alaska. The various methods used in permafrost detection are explained briefly and applications of such studies are mentioned for their importance in engineering and development. Groundwater is mentioned as being contained in permafrost although the actual detection of the water itself is not brought out in the text.

Availability
U.S. Geological Survey, Geological Survey of Canada

REFERENCE 22-2

Keywords
Permafrost, Seismic refraction, DC electrical resistivity

Technique | Interest Level
Seismic refraction, DC electrical resistivity | 2

Author
Garg, O.P., 1977, Applications of geophysical techniques in permafrost studies for subarctic mining operations: in Proceedings of a Symposium on Permafrost Geophysics, Scott, W.J., and Brown, R.J.E. (eds.), National Research Council Canada, Ottawa, p. 60-70.

Description
Determining in situ properties of frozen material in advance of the mining operation. These techniques are particularly satisfactory if high accuracy (within 15 percent) is not required.

Availability
National Research Council Canada, Ottawa, Ontario, Canada

REFERENCE 23-1

Keywords
Seismic velocities, Resistivity values, Frozen ground resistivity

Technique	Interest Level
Seismic and resistivity surveys	1

Author
Garg, Om P., 1973, In situ physicomechanical properties of permafrost using geophysical techniques: Permafrost N. American Contribution, Second International Conference, National Academy of Sciences, Washington, D.C., 1973 p. 508-516.

Description
Seismic refraction surveys and resistivity soundings were used to determine the depth of the permafrost table and base of the frozen ground, respectively in the Schefferville mining area of subarctic Canada. The seismic refraction surveys were used to provide in situ elastic properties of frozen ground. Compressional and shear wave velocities provide the various elastic constants using a mathematical relationship. Several parameters will influence the wave velocities but general pertinent conclusions can be made as follows: (1) There is a general increase in compression and shear wave velocity with decreasing temperature mainly over the range 0 to -2° C in saturated material, changes are minimal in rocks of very low water content; (2) Compared with velocities in water saturated rocks, compression velocity is lower in unsaturated rock with up to 20% porosity and even lower in the 20-80% porosity range; (3) The increase in velocities in saturated material below 0°C is probably caused by the cementing action of ice formed first in large pore spaces and progressive freezing in small pore spaces as temperature is reduced. Electrical resistivity values were analyzed to indirectly evaluate the in situ engineering properties of permafrost in the area.

The following conclusions were drawn: In frozen ground, a drastic increase in resistivity is due to frozen water in the pore spaces. Water in the unfrozen state is conductive (in this study area) while in permafrost it is highly resistive. Other conclusions were drawn pertaining to this particular study which would not have a general effect on resistivity surveys. Detailed laboratory investigations on variation of seismic and resistivity surveys as a function of temperature are required to draw precise and pertinent conclusions from field data.

Availability
National Academy of Sciences, Washington, D.C.

REFERENCE 24-3

Keywords

Sea-ice, Acoustic-measurement, Oceanographic equipment, Sound waves

Technique	Interest Level
Shear wave reflection	3

Author

Getman, J. H., and Moffett, M. B. 1973, Development of a sea-ice thickness gage; An attempt to use shear waves: U.S. Coast Guard Report USCG-D-44-75, 218 p.

Description

An experimental apparatus for the measurement of the thickness of sea-ice by the use of a shear wave reflection technique was designed and constructed. The apparatus was tested extensively in the Arctic during the summer of 1972. A portion of the apparatus, the horizontal impact source, produced reliable and repeatable excitation of the ice. Unfortunately, the measurement of the thickness of sea ice by the use of a shear wave reflection technique was not as simple as was anticipated, primarily due to the difficulty of properly exciting the ice and to the mode conversion of the acoustic energy by external and internal features of the ice.

Availability

Coast Guard Research and Development Center, Groton, Conn. 407892

REFERENCE 25-3

Keywords

Snow and ice melt, Infrared imagery, Groundwater, Springs

Technique	Interest Level
Snow and ice melt data, Infrared imagery	3

Author

Heinemann, L.R.; Myers, V.I., and Moore, D.G., 1972, Snow and ice melt as indicators of hydrologic conditions-exploratory study: Remote Sensing Institute, South Dakota State University, Interim Technical Report 72-01, 19 p.

Description

This exploratory study investigates the use of snow and ice melt as indirect indicators of groundwater occurrence and movement. Snow and ice melt patterns are useful in assessing groundwater conditions. Using a heat sink concept, the imagery provided information aiding in:

1. the delineation of shallow aquifers in glacial drift, and
2. the location of groundwater movement into rivers.

The authors feel that interpretation of snow and ice melt anomalies in combination with other remotely sensed data will strengthen capabilities in groundwater mapping.

Availability

Remote Sensing Institute, South Dakota State University, Brooklings, SD 57006

REFERENCE 26-1

Keywords
Permafrost, LF Radiohm, Inductive coupling

Technique — Interest Level
Electrical resistivity, Radiohm, Inductive coupling — 1

Author
Henderson, J.; and Hoekstra, P., 1977, Electromagnetic methods for mapping shallow permafrost: in Proceedings of a Symposium on Permafrost Geophysics, Scott, N.J., and Brown, R.J.E. (eds.), National Research Council Canada, Ottawa, p. 16-24.

Description
The purpose of the study was to test geophysical methods for delineating permafrost in the southern fringe of the discontinuous permafrost zone along the proposed Arctic Gas pipeline route. The depth of exploration required is about 10 meters. The computations show that VLF data, because of the large skin depth, are relatively insensitive to the thickness of permafrost. LF data are expected to be much better in this regard. The inductive coupling technique uses horizontal coplanar coils and the data show the technique can be expected to do well in delineating permafrost and estimating its thickness up to a maximum of 10 meters.

Availability
National Research Council Canada, Ottawa, Ontario, Canada

REFERENCE 27-3

Keywords
Bedrock detection, Permafrost, Seismic studies

Technique
Hammer seismograph

Interest Level
3

Author
Hobson, G.D., 1966, A shallow seismic experiment in permafrost, Klondike Area, Yukon Territory: Report of Activities November 1965 to April 1966 Geol. Survey Can., Paper 66-R, Ottawa, p. 10-14.

Description
A seismograph was used to test the feasibility of delineating bedrock topography favorable to the accumulation of placer gold deposits in a permafrost environment. The signal impulse was produced by placing a steel plate on the ground and striking it with a 10-pound sledge hammer. A small area near Dominion Creek was probed with the seismic method where permafrost extends to an unknown depth into bedrock. The velocity values were found to be considerably higher than those found in the same materials in non-permafrost areas. The seismic readings were taken adjacent to bore holes drilled in 22 locations 20 to 30 years earlier. Half of the seismic readings showed close correlation with bore hole data. The remaining 50% of the data showed discrepancies in depth to bedrock but close correlation in depth to gravel below muck. The seismic anomalies are explained by the presence of a layer beneath the frozen gravel which has equal or lower seismic velocity than that of the frozen gravel, thus, causing the seismic energy to be defracted downwards instead of back to the detection device.

Seismic anomalies detected in the Granville area were suspected to be due to differential thawing of the bedrock or an irregular bedding interface. Two bore holes confirmed the former interpretation.

These methods cannot accurately detect the presence of placer gold. However, benches and channels can be detected where placer gold may have accumulated. The applicability of this technique to the location of aquifers was not addressed in this article.

Availabilty
Geological Survey Canada, Ottawa, Ontario, Canada

REFERENCE 28-2

Keywords
Permafrost, Seismic refraction

Technique
Seismic refraction

Interest Level
2

Author
Hobson, G., and Neave, K.G., 1977, Permafrost distribution in the Southern Beaufort Sea as determined from seismic measurements: in Proceedings of a Symposium on Permafrost Geophysics, Scott, W.J., and Brown, R.J.E. (eds.), National Research Council of Canada, Ottawa, p. 91-98.

Description
The seismic velocities of non-saline water saturated unconsolidated sediments increase with decreasing temperatures below 0°C as a result of ice-bonding. If the sediments are coarse-grained, the transitions to higher velocities take place at permafrost temperatures, close to 0°C. In the immediate sub-sea bottom of the Beaufort shelf, this translates to a well-defined seismic discontinuity amenable to mapping by the seismic refraction technique.

Availability
National Research Council Canada, Ottawa, Ontario, Canada

REFERENCE 29-1

Keywords
Permafrost, Groundwater, Seismic refraction, Seismic reflection, Electrical resistivity

Technique
Seismic refraction, Seismic reflection, Electrical resistivity.

Interest Level
1

Author
Hoekstra, P., 1976, Geophysical methods for hydrological investigations in permafrost regions: Proceedings Second Conference on Soil-Water Problems in Cold Regions p. 75-90.

Description
The purpose of this manuscript is to relate to permafrost hydrologists the advances made in geophysical methods for investigations in permafrost regions. Geophysical methods are discussed with the aid of figures and elementary concepts, and use is made of case histories to illustrate the applicability of geophysics to permafrost hydrology. There appear to be two major areas where geophysical methods can assist hydrological investigations:

(1) In the continuous permafrost zone, securing year-round water supplies is difficult. Unfrozen zones exist at isolated locations under the braided Arctic coastal rivers, and under deeper parts of lakes. Geophysical methods were found effective in locating unfrozen zones.

(2) In the discontinuous permafrost zone, surface and subsurface drainage is to a large extent determined by the pattern of occurrence of permafrost. Vegetation is often not a good indicator of frozen ground in the southern fringe of the discontinuous permafrost zone. Geophysical methods in the Mackenzie Valley reliably delineated permafrost.

Availability
Northern Engineering Services, Ltd. Calgary, Alberta, Canada

REFERENCE 30-1

Keywords
Ground resistivity, Airborne resistivity, Permafrost

Technique | Interest Level
Ground and airborne electromagnetic resistivity | 1

Author
Hoekstra, P., and McNeill, D., 1973, Electromagnetic probing of permafrost: in Permafrost: North American Contribution, Second International Conference, Ferrians, O.J. Jr., and Hobson, G.D. (eds.), Nat'l Acad. Sci., Wash. D.C. p. 435-446.

Description
There are no apparent technological obstacles in applying the two electromagnetic survey methods - the measurement of wave tilt and the measurement of coupling between two loop antennas - to permafrost problems. The theory is well developed, and equipment design has probably reached a satisfactory level.

The two electromagnetic methods both have the advantage over the DC resistivity probing method in that they can be used from an airborne platform. The chief advantage is that reconnaissance surveys can be conducted over large areas at relatively low cost on a per-unit-area basis and in a fraction of the time required for the more conventional ground resistivity surveys.

Availability
National Academy of Sciences, Washington, D.C.

REFERENCE 31-1

Keywords
Aerial surveys, Electrical resistivity, Geological surveys, Soil surveys, Subsurface investigations

Technique
Airborne resistivity

Interest Level
1

Author
Hoekstra, P., Sellmann, P.V., and Delaney, A.J., 1974, Airborne resistivity mapping of permafrost near Fairbanks, Alaska, CRREL Research Report 324, 49 p.

Description
Airborne resistivity methods using radiowaves in three frequency bands were tested in the vicinity of Fairbanks, Alaska. The test sites were selected because much ground control is available for this area. The objectives of this study were to determine the ability of these methods to map permafrost and other soils and to investigate the advantages of multifrequency mapping. Investigations in permafrost regions for such geotechnical endeavors as route selection for roads and pipelines and site investigation for building and dam construction often require that a careful assessment be made of the presence or absence of frozen ground, of the ice content of frozen ground, and of the depth of frozen ground. The airborne resistivity data obtained in this study were contoured and the contour maps were compared with surficial geological maps and other ground truth data available. The following conclusions were reached: 1) in areas where the near-surface sediments are relatively uniform, VLF resistivity best delineates permafrost; and 2) in areas where surface sediments vary widely (e.g., recent floodplains), resistivity at all frequencies gives little information on permafrost conditions, but provides other important information, such as bedrock type, depth to bedrock, soil type and layering.

Availability
CRREL, Hanover, NH

REFERENCE 32-1

Keywords
Gravity profiling, Permafrost delineation, Groundwater detection

Technique | Interest Level
Gravity profiling, Seismic techniques, Resistivity | 1

Author
Hughes, O.L., 1975, Geology and permafrost in relation to hydrology and geophysics: Geological Survey of Canada; Dept. of Energy Mines and Resources, Calgary, Alberta. CRREL Bibliography Item 30-4421.

Description
The complexity of the geologic framework within which the hydrologist and geophysicist work is greatly enhanced in permafrost regions by the diversity of permafrost conditions, by the complex distribution of permafrost and by the complex distribution of ground ice within the permafrost.

The high cost of drilling in the unsettled northern regions will necessitate heavy dependence on geophysical techniques in any regional inventories of geology, the distribution of permafrost and ground ice, and hydrology. Emphasis will be on light, portable, and airborne instrumentation. The selection must be based on valid conceptual models of the distribution of geologic materials, permafrost, and ground ice; and the models will vary greatly according to geological, climatic and hydrologic history of the particular area concerned.

Hydrologic studies in the permafrost regions of northern Canada are still in the preliminary stages. Integrated studies of the surface active layer, and subpermafrost hydrologic regime have scarely begun. Paleohydrology study of the changing hydrology regime during development of permafrost is an important key to understanding the distribution of permafrost and ground ice, but remains an under exploited field of research.

Availability
CRREL, Hanover, NH - Permafrost Hydrology: Proceedings of Workshop Seminar Ottawa, Canada 1975 p. 21-28

REFERENCE 33-1

Keywords
Seismic refraction, Permafrost, Seismic velocities

Technique
Seismic refraction

Interest Level
1

Author
Hunter, J.A.M., 1973, The application of shallow seismic methods to mapping of frozen surficial materials in permafrost: North American Contribution, Second International Conference, Ferrians, O.J. Jr., and Hobson, G.D. (eds.), Nat'l. Acad. Sci., Wash., D.C. p. 527-535

Description
Shallow refraction seismic methods have been successfully applied to permafrost studies. Conventional instrumentation used in shallow prospecting can be applied to permafrost in summer or winter for a rapid, economical survey. Refraction spreads are generally much longer than those in permafrost-free areas to obtain the necessary depth information.

The refraction method may be used to map the occurrence of permafrost in the discontinuous zone under summertime conditions where a thawed active layer is present, because about a meter of seasonal frost at the surface in winter restricts the use of refraction methods. Structure within permafrost can be mapped with the refraction technique in conjunction with bore hole control for seismic velocities. Massive ice lenses have been delineated at depth.

Marine refraction seismic methods have been used to map the occurrence of permafrost under the sea bottom.

Availability
National Academy of Sciences, Washington, D.C.

REFERENCE 34-1

Keywords
Ice, Airborne survey, Impulse radar

Technique
Impulse radar

Interest Level
1

Author
Kovacs, A., 1978, Remote detection of water under ice - covered lakes on the north slope of Alaska, Unpublished.

Description
Results from using an impulse radar sounding system on the North Slope of Alaska to detect the existence of water under lake ice are presented. It was found that both lake ice thickness and depth of water under the ice could be determined when the radar antenna was either on the ice surface or airborne in a helicopter. Because of the significant difference between the radar signal reflection coefficient at an ice/water interface and that at an ice/soil interface it was also possible to determine where lake ice is bottom-fast and where free water still exists under the ice.

Availability
CRREL, Hanover, NH

REFERENCE 35-1

Keywords

Permafrost thickness, Geoelectricity, Electrical prospecting, Electrical resistivity

Technique | Interest Level
Audio-frequency magnetotelluric sounding | 1

Author

Koziar, A. et al., 1975, Magnetotelluric sounding of permafrost, Science, Nov. 7, Vol. 190, p. 566-568. CRREL Bibliography Item 30-2040.

Description

The audio-frequency magnetotelluric method was used to sound a permafrost region in the Mackenzie Delta in the Northwest Territories. A simple two-layer model consisting of a high electrical resistivity layer overlying less resistive material gave interpreted depths in agreement with those determined by drilling. The summer active layer was transparent even at high sounding frequencies.

Availability

CRREL, Hanover, NH

REFERENCE 36-2

Keywords

Sea ice thickness, Heat transfer

Technique | Interest Level
Infrared imagery | 2

Author

Kuhn, P.M., Stearns, L.P., and Ramseier, R.O., 1974, Airborne infrared imagery of arctic sea ice thickness: NOAA, Boulder, Col., Atmospheric Physics and Chemistry Lab.

Description

The February and March 1973 Bering Sea Ice Experiment expedition over the Arctic Ocean and Bering Sea presented correlations between infrared red thermal emission and sea ice thickness. Ice thickness was found to be inversely proportional to radiant emission and corrective heat transfer at the surface and directly proportional to ice surface and sea temperature differences at the base of the ice layer. Several applications of areal presentation of sea ice thickness include determining rates of freeze and thaw of ice, thermodynamics of the rates of ice formation and dissipation and thermal emission - thickness correlation. Possible determination of an upper snow layer is also apparent.

Availability

NOAA, Boulder, Col., Atmospheric Physics and Chemistry Lab.

REFERENCE 37-2

Keywords
Permafrost, Seismic velocities

Technique	Interest Level
Seismic velocities	2

Author

Kurfurst, P.J., 1977, Field and laboratory measurements of seismic properties of permafrost: in Proceedings of a Symposium on Permafrost Geophysics, Scott, W.J., and Brown, R.J.E. (eds.), National Research Council Canada, Ottawa, p. 1-15.

Description
This paper describes the results of laboratory and field ultrasonic measurements of compressional and shear wave velocities for several series of tests conducted on frozen soil samples from the Fort Good Hope and Norman Wells areas in the Northwest Territories.

Availability
National Research Council Canada, Ottawa, Ontario, Canada

REFERENCE 38-2

Keywords
Airborne infrared, Massive ice, Permafrost

Technique	Interest Level
Airborne infrared	2

Author
LeSchack, L.A.; Morse, I.H.; Brinley, W.R. Jr.; Ryan, N.G., and Ryan R.B., 1973, Potential use of airborne dual-channel infrared scanning to detect massive ice in permafrost: in Permafrost: North American Contribution, Second International Conference; Ferrians, O.J. Jr., and Hobson, G.D. (eds.), Nat'l. Acad. Sci., Wash. D.C., p. 542-549.

Description
The object of this research was to attempt to develop airborne techniques for ascertaining those areas of permafrost terrain that, owing to inclusions of ice lenses, wedges, strata, etc., in the permafrost, could cause severe engineering problems.

The authors conclude:

1. Single-channel IR scanning allows determination of the existence of ice wedge polygons with greater confidence than heretofore possible in areas of discontinuous permafrost or where undetectable by conventional means.

2. Dual-channel IR scanning offers even greater capabilities of identifying ice masses.

Availability
National Academy of Sciences, Washington, D.C.

REFERENCE 39-1

Keywords
Remote sensing, Ice thickness, Lake ice

Technique | Interest Level
Monocycle V.H.F. radar | 1

Author
Meyer, M.A., 1966, Remote sensing of ice and snow thickness: Adcole Corporation, Waltham, Massachusetts.

Description
A high resolution monocycle VHF radar has been developed and tested over lake ice. Tests were conducted with the U.S. Army Cold Regions Research and Engineering Laboratory using a boom as the antennae support in 1965, and using a moving helicopter as a support in 1966. Ice thickness and snow thickness were readily measured by visual data reduction. Thickness measurement accuracies on the order of 1 cm. are possible utilizing this technique. Results of measurements and the data taken are discussed as well as the expected results for such a measurement. The application of these measurements to the determination of dielectric constant is discussed.

Availability
Adcole Corporation, Waltham, Massachusetts.

REFERENCE 40-3

Keywords
Infrared imagery, Springs

Technique | Interest Level
Infrared imagery | 3

Author
Moore, D.G.; Myers, V.I.; and Giles, W.H., 1972, Location of flowing artesian wells using thermal infrared scanner imagery.

Description
Flowing springs and artesian wells were successfully mapped in a selected area within Beadle County by interpretation of February predawn thermal infrared imagery. This mapping was done under light snow cover conditions.

Availability
Remote Sensing Institute, South Dakota State University, Brookings, SD 57006

REFERENCE 41-1

Keywords
Temperature differences, Thermal image, Remote sensing

Technique | Interest Level
Thermal imagery | 1

Author
Murtha, P.A., 1971, Frost pockets on thermal imagery; Forest Management Institute, Department of Fisheries and Forestry, Ottawa, Ontario. CRREL Bibliography Item 26-1345.

Description
Sites of cooler microclimate were recorded on night time thermal imagery during overflights of a forested area in both spring and fall. The potential frost pockets appeared darkest (coldest) and ground measurements showed the sites to be as much as 5°C cooler than another open area nearby. Comparative thermal imagery and a panochromatic aerial photograph of the study area are presented.

Availability
Forest Management Institute, Dept. of Fisheries and Forestry, Ottawa, Ontario, Canada. CRREL, Hanover, NH.

REFERENCE 42-2

Keywords
Electromagnetic survey, Sea-ice thickness, Remote sensing

Technique | Interest Level
EM Radiation - VLF radio wave propagation | 2

Author
McNeil, J.D., Application of plane wave electromagnetic radiation to the measurement of sea-ice thickness: Barringer Research Ltd.

Description
This paper describes a new technique for the remote sensing of sea-ice thickness. The technique utilizes the radiation from VLF radio stations which are located at various points about the earth and which, because of their very high power and very low frequency, provide suitable signals at distances of several thousands of miles from the transmitter.

The technique measures the degree to which these waves are tilted forward by the presence of the sea-ice sheet, thus resulting in a horizontal electrical field. Theory shows that this horizontal field is directly proportional to ice thickness and essentially independent of ice resistivity and dielectric constant.

Measurement of the horizontal electric field can be performed remotely from an aircraft flying at normal geophysical survey altitude and speed (300 to 500 ft. at one hundred mph) so that a large region can be surveyed in a comparatively short time. Data reduction is extremely simple and the output presentation will consist of a contoured map of sea-ice thickness in meters.

Availability
Barringer Research Limited, Rexdale, Ontario, Canada

REFERENCE 43-1

Keywords
Soil moisture, Imaging radar, Air photos, Permafrost

Technique | Interest Level
Imaging radars and Aerial photos. | 1

Author
McDonald, H., and Waite, W. P. 1971, Soil moisture detection with imaging radars: Kansas University, Remote Sensing Lab, Lawrence Water Resources Research, Vol. 7, No. 1.

Description
The high degree of correlation between the electrical properties of soil and soil moisture content are well known. Considerable experimental work has been conducted by using radar for the determination of soil moisture. However, in the transition from a controlled measurement device to an operational imaging radar, the effects of soil moisture have been extremely difficult to separate from other terrain parameters influencing the radar return signal.

According to the authors, the data presented in this study suggest that presently available dual polarized, K-band, side-looking imaging radars provide a capability for revealing a qualitative estimate of soil moisture content. When used as a supplement to aerial photography in temperate climates, radar imagery analysis will decrease the ambiguity of soil type reconnaissance. In the Arctic, an imaging radar may provide data for mapping regions of permafrost, and this process could be accomplished in a sequential manner regardless of weather or time of day. The use of additional multifrequency multipolarization imaging radars and the relative foliage penetration of each should be investigated as a possible means of gathering quantitative soil moisture information.

Availability
University of Kansas - Remote Sensing Lab, Lawrence, Kansas 66044

REFERENCE 44-2

Keywords
Radio-echo, Glacier

Technique | Interest Level
Radio-echo sounder | 2

Author
Nelson, D. E., 1969, Radar sounding of glaciers in the Icefield Ranges: Department of Electrical Engineering, Massachusetts Institute of Technology, Cambridge, Mass. CRREL Bibliography Item 25-4193.

Description
An experiment was performed to determine the usefulness of the Scott Polar Research Institute Mark II Radio Echo Sounder in mapping and studying the glaciers in the Icefield Ranges of the St. Elias Mountains. When the apparatus is operated above a glacier, either on the surface or from an airplane, reflections occur at the surface, at internal inhomogeneities, and at bedrock. The distances to the corresponding reflective surfaces can then be determined if the signals have not been distorted. A main objective of the test was to determine the limiting factors of the sounder related to clutter from valley walls, wet surface snow and streams, and highly fractured and crevassed areas.

Availability
Dept. of Electrical Engineering - Mass. Institute of Technology, Cambridge, Mass. CRREL, Hanover, NH.

REFERENCE 45-2

Keywords
Ground temperature, Permafrost, Groundwater

Technique | Interest Level
Ground temperature observations | 2

Author
Nicholson, F.H., and Lewis, J.S., Active layer and suprapermafrost groundwater studies: Schefferville, Quebec.

Description
Ground temperature observations indicate that active layer depth is usually related to surface cover, typical values being 2.4 m under continuous vegetation and 3.6 m under bare ground. However, under drainage lines the active layer is usually much deeper (often 10 to 12 m) or a talik zone may be present (typically 15 to 30 m), and it is thought that this is due to the transport of heat by suprapermafrost groundwater. Ground temperatures, water table height and related data were collected over a summer in a small catchment containing a zone of deep thaw, with a view to producing subsurface heat and water budgets. The results indicate that heat conduction alone can account for the thermal flux on average sites but cannot account for the deep active layers; that much of the groundwater movement is through limited zones of high permeability; and that there is substantial suprapermafrost groundwater movement through the deep active layer and talik zones.

Availability
Subarctic Research Laboratory, Schefferville, Quebec, Canada, and Dept. of Geography, McGill University, Montreal.

REFERENCE 46-1

Keywords
Radar, Permafrost detection, Permafrost structure, Lake ice

Technique
GSSI Impulse radar

Interest Level
1

Author
Olhoeft, G.R., 1978, Effects of permafrost on roads and pipelines; utilizing GSSI radar: U.S. Geological Survey, Denver, Colorado, Personal Communication.

Description
Field testing of the Geophysical Survey Systems Inc. (GSSI) radar was conducted in the spring of 1978 on the north slope of Alaska near Barrow. The portable ground based unit was used to determine lake ice thickness, depth to permafrost, and thawed areas in.permafrost. The unit provides a continuous readout and early report of results is very encouraging for future use of this instrument. Results of the recently completed study will be presented at the 3rd International Permafrost Conference to be held in Edmonton, Alberta in July 1978. No published information was yet available for inclusion in this study. The GSSI radar has previously been used for the airborne determination of sea-ice thickness.

Availability
U.S.Geological Survey, Petro physics and Remote Sensing Divison, Denver, Colorado.

REFERENCE 47-2

Keywords
Infrared imagery, Groundwater, Hydrology

Technique
Infrared imagery

Interest Level
2

Author
Pluhowski, E.J., 1972, Hydrologic interpretations based on infrared imagery of Long Island, New York: U.S. Geological Survey, Water Supply Paper 2009-B, p. 26.

Description
Six remote-sensing flights over Long Island's north and south shores were made during the period July 13, 1967, to February 25, 1970. Infrared imagery in the 8- to 14-micrometer range was obtained; results varied from poor to excellent in quality.

The ability of the RS 7 and Reconofax IV imagers to discern thermal contrasts of as little as 1° to 2°C permitted identification of areas of heavy groundwater discharge. These areas were concentrated primarily along the eroded headlands of the north shore and in the lower reaches of water-courses draining into the Great South Bay. Only a few highly localized examples of direct groundwater discharge into the embayments along Long Island's south shore were detected in the imagery.

Thermal loading emanating from a powerplant near Oceanside is shown to be quickly dissipated in Middle Bay. Specific examples show that infrared imagery may also be used to identify circulation patterns, ice cover, changes in stream-temperature regimen, and the location of sewer outfalls. Optimal time for the collection of infrared imagery for hydrologic studies on Long Island is in summer and in winter, when surface-water thermal differences are relatively large.

Availability
U.S. Geological Survey, Arlington, VA 22202

REFERENCE 48-1

Keywords
Infrared imagery, Permafrost, Sea ice, Water supply

Technique: Thermal infrared imagery

Interest Level: 1

Author
Poulin, A. O., 1976, The potential of thermal infrared imagery for supplemental map information in snow-covered areas: Army Engineer Topographic Labs, Fort Belvoir, VA., 43 p.

Description
Thermal infrared imagery is used to map surface temperature changes in snow-covered areas. The various processes involved in surface temperature change are discussed in terms of energy transfer and magnitude. The uses of the map are briefly summarized and include determination of concealment areas, land navigation, and water supply. The latter is determined by those lakes which do not appear to be frozen to their total depths.

Availability
Army Engineer Topographic Labs, Fort Belvoir, VA.

REFERENCE 49-3

Keywords
Seismic detonation, Permafrost

Technique: Low noise seismic detonation

Interest Level: 3

Author
Rackets, H.M., 1971, A low noise seismic method for use in permafrost regions: Geophysics, Vol. 36, No. 6, p. 1150-1161. CRREL Bibliography Item 26-2992.

Description
A seismic technique utilizing dynamite charges of 1 to 2 lb. detonated at depths of 5 to 10 ft. below the ground surface proved to eliminate or greatly reduce the occurrence of frost breaks which tended to occur with greater charges. Rackets says the advantages to this technique are a cost reduction of 10 percent or more by reduction of drilling equipment and the ability to employ light-weight portable seismic crews in remote areas. A number of small charges were detonated at each geophone location (156 one-lb shotpoint locations per mile). The total profile distance was sufficient to allow for one-half mile of fully stacked subsurface coverage. The experiment results compare favorably with those from the high charge conventional method.

Availability
Geophysics, CRREL Hanover, NH.

REFERENCE 50-2

Keywords
Remote sensing, Ice thickness, Permafrost, Terrain analysis

Technique	Interest Level
Gravity profiling	2

Author
Rampton, V.N.; Walcott, R.I.; 1974, The detection of ground ice by gravity profiling: Symposium on Permafrost Geophysics, National Research Canada, Technical Memo 113, p. 60-61. CRREL Bibliography Item 30-803.

Description
The purpose of the gravity profiling in the Tuktoyaktuk Peninsula and Eskimo Lakes regions was to determine if excess ice and its thickness could be estimated by this method and to determine if certain geomorphic features were due to the presence of excess ice or some other causative factor. Bouger anomalies were used to indicate relation to elevation of a point which in turn was related to amount of excess ice. Total ice thickness was then obtained by applying theoretical parameters as well as supplementary geologic information. Limitations of this technique are: (1) linear trends in excess ice thickness over the complete profile are difficult to detect; and (2) slabs of ice underlying the complete profile are impossible to detect unless a portion of the profile crosses an area free of permafrost.

Availability
CRREL, Hanover, NH

REFERENCE 51-1

Keywords
Seismic refraction, Permafrost thickness, Glacial deposits, Seismic velocity

Technique	Interest Level
Seismic refraction	1

Author
Roethlisberger, H., 1961, The applicability of seismic refraction soundings in permafrost near Thule, Greenland: CRREL Technical Report 81

Description
The applicability of the seismic refraction method for engineering purposes was investigated in the Thule area of Greenland. Special attention was given to the cases in which shallow ice overlies frozen ground and in which frozen glacial drift up to a few hundred feet thick overlies bedrock. Seismic velocities were measured in different types of sediments in the "Thule formation" and in the crystalline basement rock. The velocities in rock and frozen ground were generally high, cementation by ice being the most likely reason of the relatively low ground temperatures of -1°C. It was found that, with comparable velocity discrimination, the refraction method gives more complete information in permafrost than in unfrozen material, since later seismic events can be identified on the records shortly after the first arrival. Later events also made wide angle reflection soundings possible at a depth as shallow as 200 ft. A negative velocity gradient in the frozen ground is believed to be responsible for the rapid attenuation of the direct wave.

Availability
CRREL, Hanover, NH

REFERENCE 51-2

Keywords
Elastic waves, Frozen soil, Geophysical surveys

Technique | Interest Level
Seismic reflection, Seismic refraction | 2

Author
Roethlisberger, H.; 1972, Seismic exploration in cold regions. CRREL Monograph II-A2a.

Description
This monograph contains a comprehensive review of the use of seismic methods and related techniques based on elastic waves, to gain information on the geometry and physical properties of the substrata in cold regions, particularly snow, ice, and frozen ground. Pertinent elastic properties of these materials are described and methods for determining seismic velocities are summarized. Theories and application of reflection and refraction soundings on glaciers, continental ice sheets, ice shelves, and frozen ground are reviewed. Surveys employing surface waves, and special application of elastic waves are described.

Availability
CRREL, Hanover, NH

REFERENCE 52-1

Keywords
Ice thickness determination, Remote sensing, Echo sounding

Technique — Interest Level
Ultrasonic echo sounding — 1

Author
Roethlisberger, H., 1966, Ultrasonic pulse measurements in anisotropic lake ice: CRREL Research Report 126.

Description
In March of 1960, travel-time measurements of ultrasonic pulses were taken on Lake Superior near Baraga, Michigan. The pulses were transmitted and received by barium titanate cells through ice of 45 cm thickness. The transceiver was mounted at various distances on the surface. A number of direct and reflected signals could be identified. The PS type proved to be the clearest and strongest for ice thickness determination. Some observed reflections were from cracks in the ice. Using equipment with 100 kHz signals the ice thickness was determined with accuracy of 2 to 4 cm or 5-10%. For day to day comparisons, the relative accuracy would be in the order of 0.5 cm.

Availability
CRREL Hanover, NH

REFERENCE 53-2

Keywords
Permafrost, Seismic velocities, Seismic reflection, Seismic refraction

Technique — Interest Level
Seismic reflection, Seimsic refraction — 2

Author
Rogers, J.C., 1977, Seismic investigation of offshore permafrost near Prudhoe Bay, Alaska: in Proceedings of a Symposium on Permafrost Geophysics, Scott, W.J., and Brown, R.J.E. (eds.), National Research Council Canada, Ottawa, p. 71-90.

Description
The study describes locating the permafrost surface dipping offshore to a depth of approximately 100 m. Delineation of the upper surface was done due to a marked difference in seismic velocity between the frozen material and the unfrozen material.

Availability
National Research Council Canada, Ottawa, Ontario, Canada

REFERENCE 54-1

Keywords
E-M sounding, Permafrost, Magnetotellurics

Technique | Interest Level
Magnetotellurics, Radio frequency interferometry | 1

Author
Rossiter, J.R., Electromagnetic sounding in permafrost terrain: C-CORE, Memorial University of Newfoundland, St. John's, Newfoundland, Canada.

Description
In situ properties of permafrost were studied using the above mentioned techniques. The audio frequency magnetotelluric method proved to be a good method to determine permafrost thickness utilizing a model consisting of a resistive layer overlying a conductive layer. Radio frequency interferometry did not provide good layering information but the effects of snow in winter were seen as interference at 32 MHz. The unfrozen active layer was undetectable by these two methods. The 3rd method utilized monopoles imbedded in the surface layer to determine dielectric constant and loss tangent. The dielectric constant was shown to be higher than that of dry soils in both summer and winter months indicating moisture in the active layer even at -28°C.

Availability
Memorial University of Newfoundland, St. John's, Newfoundland, Canada

REFERENCE 55-1

Keywords
Groundwater, Surface resistivity, Aquifer delineation

Technique | Interest Level
Surface resistivity | 1

Author
Schwartz, F.W., and McClymont, G.L., 1977, Applications of surface resistivity methods: Groundwater, Vol. 15, p. 197-202.

Description
Resistivity highs in the Breton area are related to the presence of a local sandstone acquifer at a shallow depth. The profile mapping method in this area provided a rapid and inexpensive method of outlining this aquifer. Surveys in the Hastings Lake area determined that resistivity patterns could be correlated with regional patterns at grain-size variation. The marked station-to-station variability in apparent resistivity resulted from a local variation in drift texture.

Availability
Groundwater, Urbana, Illinois

REFERENCE 56-1

Keywords
Permafrost, DC resistivity

Technique | Interest Level
DC Resistivity (Schlumberger technique) | 1

Author
Scott, W.J., 1977, Reliability of permafrost thickness determination by DC resistivity sounding: in Proceedings of a Symposium on Permafrost Geophysics, Scott, W.J., and Brown, R.J.E., (eds.), National Research Council of Canada, Ottawa, p. 25-38.

Description
The contrasts in resistivity at the base of the active layer and at the base of permafrost are both extremely high. Because of this, it is necessary to have a great thickness of permafrost resistivity. Unless there is independent control of either thickness or resistivity, a sounding in an area of thin permafrost will not yield a unique value of permafrost thickness.

Availability
National Resource Council of Canada, Ottawa, Ontario Canada

REFERENCE 57-1

Keywords
Permafrost, Geophysical techniques

Technique | Interest Level
All geophysical techniques | 1

Author
Scott, W.J., and Brown, R.J.E., 1977, Proceedings of a Symposium on Permafrost Geophysics: National Research Council of Canada, Ottawa, Technical Memo 119, p. 144.

Description
This is a record of a symposium on permafrost geophysics held October 12, 1976, at Vancouver, British Columbia. The meeting was the third on this topic and was sponsored by the Permafrost Subcommittee, Associate Committee on Geotechnical Research, National Research Council of Canada.

The series of papers summarizes the "state-of-the-art" for using geophysical methods for the delineation of the distribution of permafrost. Techniques described included seismic refraction, seismic reflection, VLF and LF radiohm, inductive coupling, DC electrical resistivity, magnetic induction, and ground probing radar.

Availability
National Research Council Canada, Ottawa, Ontario, Canada

REFERENCE 58-2

Keywords
Massive ice, Radar impulse, EM-sounding, Permafrost detection

Technique
E-M impulse radar system

Interest Level
2

Author
Scott, W.J.; Campbell, K.J. and Orange, A.S., 1974, E.M. pulse survey method in permafrost: National Research Council Canada, Technical Memo No. 113. CRREL Bibliography Item 30-813.

Description
Impulse radar was used to try to determine ground and ice thickness. The area studied contained frozen clayey till overlying frozen sands. Thickness of till could be determined with some accuracy; however, thickness of ice could not. Reflections could have been caused by the change to massive ice or interlayered clay and ice. Further field work is necessary to come up with conclusive results.

Availability
CRREL, Hanover, NH

REFERENCE 59-3

Keywords
Aerial survey, Allagash, Maine, Electrical resistivity, Geophysics, Structural geology, Subsurface Investigations

Technique
Airborne VLF resistivity and magnetometer

Interest Level
3

Author
Sellmann, P.V., Arcone, S.A., and Delaney, A. W., 1976, Airborne resistivity and magnetometer survey in northern Maine for obtaining information on bedrock geology. CRREL Report 76-37, 24 p.

Description
Geophysical studies were conducted during September and October of 1975 in northern Maine to locate rock types suitable for construction purposes for the proposed Dickey-Lincoln School Dam Project. Simultaneous airborne magnetometer and VLF electrical resistivity surveys were performed over an area of approximately 920 km^2 surrounding the confluence of the St. John and Allagash rivers. The resulting data were used to construct contour maps of apparent resistivity and of total magnetic intensity above the earth's background magnetic field. During the same time period, ground and multi-elevation surveys were performed over a special test sector of known geology. The ground and airborne study in the test sector aided in interpretation of the data by revealing a strong correlation between igneous geology, resistivity, and magnetic intensity. Lack of a similar correlation between resistivity and magnetic data in the remainder of the survey area suggested an absence of additional areas of igneous rocks. The multi-elevation survey of the test area indicated that changes in flight altitude, necessitated by the topographic relief encountered, would not seriously affect the regional resistivity patterns. Although there was no strong evidence of igneous rocks outside the test sector, suitable rock types may exist within the Dss geologic unit (cyclically bedded gray slate and sandstone) in the central part of the main survey area, where most of the high resistivity contours occur.

Availability
CRREL, Hanover, NH; U.S. Geological Survey, Arlington, VA 22202.

REFERENCE 60-2

Keywords
Permafrost, LF radiohm, Magnetic induction

Technique | Interest Level
Electrical resistivity, Radiohm, Magnetic inductive | 2

Author
Sellman, P.V., Arcone, S.A., and Delaney, A., 1977, Preliminary evaluation of new LF radiowave and magnetic induction resistivity units over permafrost terrain: in Proceedings of a Symposium on Permafrost Geophysics, Scott, W.J., and Brown, R.J.E. (eds.), National Research Council of Canada, Ottawa, p. 39-42.

Description
The results obtained in this preliminary evaluation indicate that both of these tools have potential applications in permafrost environments. They appear suited for obtaining data on permafrost distribution and general characterization of ground conditions at shallow depth, in some geological settings.

Availability
National Research Council of Canada, Ottawa, Ontario, Canada

REFERENCE 61-2

Keywords
Arctic Coastal Plain, Alaska, Ice, Images, Lakes, Permafrost, Satellites (artificial), Thaw lakes.

Technique | Interest Level
ERTS-1, Aerial photography | 2

Author
Sellmann, P.V., Brown, J., Lewellen, R.I., McKim, H., and Merry, C., 1975, The classification and geomorphic implications of thaw lakes on the arctic coastal plain. Alaska, CRREL Research Report 344, 24 p.

Description
The lakes of the Arctic Coastal Plain of northern Alaska were classified, based on size, shape, orientation and distribution, into six lake units and three nonlake units. Regional slope and relief were demonstrated to control lake size, the largest lakes occurring on the flattest, northernmost segment of the Coastal Plain. Using ERTS-1 sequential imagery and existing photography and data, lakes were grouped according to three depth ranges, <1 m, 1-2 m and >2 m. Deepest lakes have the longest period of summer ice cover. Ice on shallow lakes melts the earliest. Maximum depths of lakes were computed based on ice volume content of the perennially frozen ground (permafrost) and these agreed with observed values and ranges. The lake classification and regional ERTS-1 coverage also appear to provide additional information on the limits of the late-Pleistocene transgressions on the Coastal Plain.

Availability
CRREL, Hanover, NH.

REFERENCE 62-3

Keywords
Aerial surveys, Allagash, Maine, Electrical resistivity, Geological surveys, Soil surveys, Subsurface investigations

Technique	Interest Level
VLF resistivity	3

Author
Sellmann, P.V., Delaney, A.J., and Hoekstra, P., 1975, Radiowave resistivity measurements in northern Maine for identifying bedrock type, CRREL Special Report 238, 15 p.

Description
A preliminary ground resistivity survey using the VLF radiowave method was conducted in northern Maine near the site of the proposed Dickey-Lincoln dam and hydroelectric project. This survey was intended to establish if adequate resistivity contrasts exist between bedrock types in the area to warrant further bedrock distribution studies by airborne resistivity techniques. A more complete understanding of the geology of this area was considered necessary in an attempt to located rock types suitable for construction purposes near the proposed construction sites. Field observations were made on all rock types commonly found in the area, including the dominant gray slates and the less common orthoquartzites and granodiorites. The granodiorites are considered most suitable for construction purposes. Results of the field study suggest that an airborne survey could differentiate between the granodiorites and the surrounding gray slates in areas of shallow overburden, although resistivity contrasts between the slates and the orthoquartzite were probably not great enough to differentiate between these rock types. More than 70% of the resistivity values from the granodiorite sites exceeded 10,000 ohm-m; in contrast, approximately 8% of the slate values and none of the orthoquartzite values exceeded 10,000 ohm-m. A VLF resistivity profile was also obtained along a segment of the southern section of the proposed dam centerline. Resistivity values correlated well with subsurface information obtained during earlier Corps of Engineers drilling investigations. Major breaks in the resistivity data agreed with variations in ground conditions such as increases in till thickness over bedrock and the occurrence of silt and clay in the valley of the Saint John River. Resistivities ranged from 100 to 9000 ohm-m along the line. The lowest values were associated with the silts and clays and the highest with areas where bedrock is near the surface.

Availability
CRREL, Hanover, NH 03755.

REFERENCE 63-1

Keywords
Ice, Images, Lakes, Side-looking radar, Thickness

Technique
Side-looking airborne radar

Interest Level
1

Author
Sellmann, P., Weeks, W.F., and Campbell, W.J., 1975, Use of side-looking airborne radar to determine lake depth on the Alaskan north slope: CRREL Special Report 230, 10 p.

Description
Side-looking airborne radar (SLAR) imagery obtained in April-May 1974 from the North Slope of Alaska between Barrow and Harrison Bay indicates that tundra lakes can be separated into two classes based on the strength of the radar returns. Correlations between the areal patterns of the returns, limited ground observations on lake depths, and information obtained from ERTS imagery strongly suggest that freshwater lakes giving weak returns are frozen completely to the bottom while lakes giving strong returns are not. Brackish lakes also give weak returns even when they are not completely frozen. This is presumably the result of the brine present in the lower portion of the ice cover limiting the penetration of the X-band radiation into the ice. Although the physical cause of the differences in radar backscatter has not been identified, several possibilities are discussed. The ability to rapidly and easily separate the tundra lakes into these two classes via SLAR should be useful in a wide variety of different problems.

Availability
CRREL, Hanover, NH; U.S. Geological Survey, Arlington, VA 22202

REFERENCE 64-1

Keywords

Permafrost mapping, Permafrost delineation, Dielectric properties, Electromagnetic survey

Technique | Interest Level
Electromagnetic dipole | 1

Author

Sinha, A.K., 1976, Determination of ground constants of permafrost terrains by an electromagnetic method: Canadian Journal of Earth Science, March, Vol. 13. CRREL Bibliography Item 30-3419.

Description

The generalized solution of the scattering of electromagnetic fields by an n-layer earth in the presence of oscillating magnetic dipoles carrying harmonic currents has been obtained. The solutions are valid for all frequency ranges and for arbitrary parameters of the n-layer earth. The results have been expressed in six infinite integrals, four of which depend on the transverse electric modes and the rest on the transverse magnetic modes. These solutions have been used to obtain the generalized expressions for the mutual coupling ratios for 5-coil systems most often used in the geophysical industry.

Using the solutions, a study has been made on the relative performance of the five coil systems for mapping permafrost terrains by multifrequency techniques, assuming the earth to be a homogeneous lossy dielectric, which may be a valid model in winter. It has been observed that the responses in all five coil systems are quite similar, but the magnitude of the response is largest in the horizontal coplanar system. A graphical technique of obtaining the resistivity and dielectric constant of the ground from the mutual coupling ratios has also been described. The results would be useful for designing portable multifrequency E.M. dipole systems for the detection and delineation of permafrost at high latitudes. The inclined, parallel, null-coupled system comes next in order of preference for the mapping of permafrost terrain, followed by the vertical coplanar and the perpendicular systems.

Availability

CRREL, Hanover, NH

REFERENCE 65-2

Keywords
EM sounding, Permafrost, Resistivity

Technique | Interest Level
EM sounding | 2

Author
Sinha, A.K., Electromagnetic sounding in permafrost regions: Geological Survey of Canada, Paper 74-1, Part B.

Description
A study was initiated to consider the applicability of using the mutual coupling ratios of loops energized by harmonic currents for the determination of the electrical parameters of the ground in the permafrost zones. The purpose of the study was to compare the response in all 5 coil systems and decide which one would serve the purpose of determining the electrical characteristics of the permafrost zone. The other purpose was to find a way of determining electrical constants from the mutual coupling ratios measured at several frequencies. Keeping one coil horizontal and the other vertical at specified distances and frequencies provided apparent resistivity and apparent dielectric constant of the medium for a layered medium and true resistivity and dielectric constant for a homogeneous medium at 1 MHz. Resolution deteriorates as high resistivity values are encountered.

Availability
Geological Survey of Canada, Ottawa, Ontario, Canada

REFERENCE 66-1

Keywords
Remote sensing, Echo sounding, Electrical properties of ice and water

Technique | Interest Level
Radio-echo sounding | 1

Author
Smith, B.M. Ewen, 1971, Radio echo sounding: Absorption and scattering by water inclusion and ice lenses: Journal of Glaciology, Vol. II, p. 72-79.

Description
The absorption of radio waves propagating through naturally occurring waters varies greatly with the electrical conductivity. Glacier melt water is very transparent and the attenuation by melt water layers is due to reflection of power, whereas, the attenuation of sea water layers is due to absorption. The attenuation of soaked firn is usually prohibitive if the liquid is brine but it should not be a serious obstacle to radio echo strength if the liquid is rain water or melt water. However, the magnitude of the scattered power can become greater than that from continuous bedrock reflectors if the size of the irregularities on the medium is large approaching the radio wavelength in ice. Echo power formulae show that ice lenses may have the most serious effects and that low radio frequencies may be necessary to combat this.

Availability
Journal of Glaciology, Cambridge, England

REFERENCE 67-2

Keywords
Seismic reflection, Permafrost, Seismic refraction

Technique
Seismic reflection and refraction

Interest Level
2

Author
Smith, G.W. and Rempel, G., 1974, Review of problems of exploration geophysics in permafrost: CRREL Bibliography Item 30-811

Description
Seismic reflection is a popular method for prospecting in the oil and gas industry. Seismic refraction is used in specialized cases to locate the top surface of permafrost when it lies beneath a water body. Permafrost is of concern to geophysicists when it distorts the picture of what lies beneath in more prospective geologic horizons. Seismic velocities dramatically increase in saturated soils from the thawed to the frozen state. A significant gradual increase in velocity is apparent as temperature is lowered. This is due to the amount of unfrozen water contained in the transition zone from thawed to frozen state. A significant gradual increase in velocity is apparent as temperature is lowered. This is due to the amount of unfrozen water contained in the transition zone from thawed to frozen states. Permafrost characteristics are highly variable in extent due to proximity to heat sources such as water bodies. Distribution of permafrost and its velocities can be used to detect anomalies and their associated effects on engineering.

Availability
CRREL, Hanover, NH

REFERENCE 68-1

Keywords
Resistivity contrasts, Pollution, Groundwater

Technique
Resistivity survey

Interest Level
1

Author
Stollar, R.L., and Roux, P., 1974, Earth resistivity surveys - A method for defining ground-water contamination: 26th Annual National Water Well Assoc. Convention, Denver, Col. p. 145-150.

Description
An important part of every investigation of groundwater pollution is to locate and define the extent of the contaminated body of groundwater. The usual method for accomplishing this is to install and sample numerous test wells, a costly and time-consuming procedure. A much faster and less costly method, which has proven to give accurate results, is the earth resistivity survey. Because earth resistivity is inversely proportional to groundwater conductivity, the location of groundwater that has been contaminated by a relatively high concentration of conductive industrial wastes, for example, may be quickly and accurately traced.

In order for the resistivity method to give useful results, resistivity contrasts must exist in the subsurface. For example, if the contaminant does not have a significantly greater conductivity than the natural groundwater, or if the groundwater is naturally highly conductive itself, a large enough resistivity contrast may not exist, and the method may not work. In addition, if depth to water is too great, the thickness of the unsaturated sediments can mask any contrasts between contaminated and natural groundwater. The geologic environment must be relatively uniform so that the resistivity values and profiles can be compared with one another. At most industrial plant sites and landfills, these conditions are met. That is, the area of investigation is usually limited to a few hundred acres, where the geology and depth to water tend to be uniform.

Four case histories of industrial and landfill sites are discussed in this paper. In three of the cases, the results of the earth resistivity studies, which were verified by installing test wells in and around the area being investigated, proved to be remarkably accurate. In the fourth study, the conditions mentioned were not met, and the survey was unsuccessful.

Availability
Groundwater, Vol. 13, N.2

REFERENCE 69-2

Keywords
Ice thickness, Microwave radiometer

Technique
Microwave radiometer

Interest Level
2

Author
Tiuri, M., Laaperi, A., and Jokela, K., 1975, Passive radiowave sensing of the thickness and other characteristics of sea ice: in Proceedings of the International Symposium on Remote Sensing of Environments, Ann Arbor, Mich., p. 633-636.

Description
During the spring of 1975, an extensive experiment to determine the characteristics of sea ice in the Baltic Sea by passive and active remote sensing methods was performed. The preliminary results of UHF and microwave radiometer measurements indicate that 600 MHz and 5 GHz radiometers can be used to determine the ice thickness in the case of relatively low salinity ice.

Availability
Environmental Research Institute of Michigan, Center for Remote Sensing Information and Analysis

REFERENCE 70-2

Keywords
Holographic survey, Satellite, Permafrost

Technique
Multispectral imagery, Thermal scanners, Holographic ice surveying system

Interest Level
2

Author
Tarnocal, C., and Thie, J. 1974, Application of remote sensing to permafrost studies: National Research Council Canada, Technical Memo 113, p.43-47. CRREL Bibliography Item 30-808.

Description
Several techniques were used to determine the presence and extent of permafrost in Northern Manitoba. Each technique had certain value and also was subject to its own limitations. None of the techniques were used to determine depth to permafrost or thickness of frozen ground. The authors indicate that it is possible to estimate the ice content by applying knowledge concerning the landform, soil, and vegetation.

Availability
CRREL, Hanover, NH

REFERENCE 71-3

Keywords
Remote sensing, Road-icing, Ice detection

Technique | Interest Level
Surface Condition Analyzer (SCAN) | 3

Author
____________, Report on a field test of surface condition analyzer: U.S. Forest Service, Rocky Mt. Forest and Ranger Experiment Sta., Fort Collins, Colorado. CRREL Bibliography Item 30-799.

Desciption
The surface condition analyzer provides information about surface conditions pertaining to temperature and moisture. By setting the threshold of precipitation to an adequate sensitivity for expected conditions, proper readings of "wet," "dry," and "ice" will register reflecting surface conditions. A sensor is placed flush with the surface and will mirror conditions at that spot. Several sensors would be needed to give an accurate picture of surface conditions covering a wide area.

Availability
CRREL, Hanover, NH.

REFERENCE 72-3

Keywords
Landforms, Subsurface geology, Permafrost, Groundwater

Technique | Interest Level
Subsurface drilling | 3

Author
Williams, J.R., 1970, Groundwater in the permafrost regions of Alaska: U.S. Geological Survey, Prof. Paper 696, 83 p.

Description
Although groundwater in permafrost regions in Alaska occurs according to the same geologic and hydrologic principles prevailing in temperate regions, subfreezing temperatures result in profound modification of groundwater flow systems. Frozen ground in many areas eliminates shallow aquifers and requires that wells be drilled deeper than in similar geologic environments having no permafrost. Groundwater occurs above, below and locally within, permafrost. In the continuous-permafrost zone, the most economically developed sources of water are in unfrozen alluvium beneath large lakes and rivers. In the discontinuous-permafrost zone, groundwater is produced locally from shallow aquifers above permafrost of offshore bars and spits because water within or below the frozen beach deposits is saline. Elsewhere, potential contamination of shallow aquifers makes desirable a source of water beneath the frozen layer. In major valleys and in many smaller upland and mountain valleys, groundwater is available in alluvium beneath permafrost or in unfrozen alluvium beneath or adjacent to riverbeds. The frozen layer is generally thicker and areally more extensive beneath terraces than beneath floodplains. Limited data suggest that the base of the frozen layer is commonly above the water table beneath the apexes of alluvial and outwash fans in major valleys. In coastal plains and in lowlands underlain by glacial and glaciolacustrine deposits, the complex stratigraphy is paramount in controlling the movement and storage of groundwater. In some areas, however, water movement is controlled by impermeable permafrost boundaries; and where the frozen ground extends into bedrock, the unconsolidated deposits are unproductive.

Groundwater is obtained from unfrozen bedrock above or beneath permafrost in mountains and uplands and, locally, in some valleys where the unconsolidated deposits are frozen or are too fine grained to yield water.

Availability
U.S. Geological Survey, Arlington, VA 22202

REFERENCE 73-3

Keywords
Groundwater, Water resources, Permafrost, Icings

Technique | Interest Level
Soil-moisture cells, Piezometers, Observation wells | 3

Author
Williams, J.R., and van Everdinger, R.O., 1973, Groundwater investigations in permafrost regions of North America: A review: in Permafrost: North American Contribution, Second International Conference, Ferrians, O.J. Jr., and Hobson, G.D. (eds.), Nat'l. Acad. Sci., Wash. D.C. p. 435-446.

Description
This review article discusses the control that permafrost exerts over the movement of groundwater. This includes the availability of groundwater in alluvial deposits and bedrock as well as major fresh water springs and thermal springs. Icings, pingos, and artesion pressures are discussed.

The role of permafrost in directly imparting a particular type of mineralization to groundwater is probably minor. Shallow groundwater in the permafrost regions is generally of the calcium or calcium magnesium bicarbonate type. In alluvium of interior valleys high concentrations of iron and manganese, high organic content with resulting color and odor as well as excess hardness, are the main objectionable qualities of the water, most of which is otherwise suitable for most domestic and industrial uses. The deep groundwater below permafrost is usually of a relatively constant quality.

The boundaries of the temperature defined permafrost do not coincide with those of frozen ground. Soil-moisture cells containing thermistors have been sucessfully used to monitor development of the frozen ground and dissipation of freezing ground.

If free groundwater is present in permafrost or in seasonally freezing or thawing layers above and below permafrost, measurement of pressures in the liquid phase can detect transient hydraulic gradients that govern movement of free groundwater. Observation wells and piezometers can be use. An alternative method to measure pressures uses electrical, hydraulic, or pneumatic pressure transducers.

Availability
National Academy of Sciences, Washington D.C.

REFERENCE 74-1

Keywords
Groundwater determination, Hydrogeology, Aquifer location, Gravity anomalies

Technique — Interest Level
Gravimeter — 1

Author
Zohdy, A.A.R.; Eaton, G.P.; and Mabey, D.R., 1974, Application of surface geophysics to groundwater investigations: Techniques of Water-resources Investigations of the U.S.G.S., Book 2, Chpt. D1.

Description
The gravity method of determining subsurface geology and hydrogeology is explained in theory and practice. Density contrast between layers of strata is the basis of gravity determination. The gravity method may be applied to determination of aquifer thickness and geometry as well as total density and porosity of a rock mass.

Availability
U.S. Gov't. Printing Office, Wash. D.C. 20402, Stock Number 2401-02543

REFERENCE 75-1

Keywords
Seismic reflection, Seismic refraction, Hydrogeologic mapping, Groundwater determination

Technique — Interest Level
Seismic reflection and refraction — 1

Author
Zohdy, A.A.R.; Eaton, G.P.; and Mabey, D.R., 1974, Application of surface geophysics to groundwater investigations: Techniques of Water-resources Investigations of the U.S.G.S., Book 2, Chpt. D1.

Description
The method of seismic reflection and refraction are described in theory and in practice. They are compared and contrasted as to their use on a horizontally-layered isotropic model. Whereas the reflection method is more commonly used in petroleum exploration, the refraction method is only accurate where a stratum of higher seismic velocity lies below a stratum of lower velocity. This is reasonably expected in areas of thick glacial or alluvial fill. Areas with steeply dipping boundaries are best delineated using the refraction method as well. The report summarizes seismic refraction methods effects and applications in hydrogeology.

Availability
U.S. Gov't. Printing Office, Wash. D.C. 20302, Stock Number 2401-02543

REFERENCE 76-1

Keywords
Resistivity survey, Groundwater detection, Electromagnetic survey, Magnetotelluric survey, Hydrology

Technique | Interest Level
Electrical methods | 1

Author
Zohdy, A.A.R.; Eaton, G.P.; and Mabey, D.R.; 1974, Application of surface geophysics to groundwater investigations: Techniques of Water-resources Investigations of the U.S.G.S., Book 2, Chpt. D1.

Description
Several electrical methods for determining subsurface geologic and hydrogeologic properties are explained in this section of the book. Five methods are outlined and their applications described. These methods are telluric current, magneto-telluric, direct-current resistivity, induced polarization, and electromagnetic surveys. Resistivity surveys appear to be the most promising in the area of groundwater studies. The report dwells briefly on its application in mapping buried stream channels, fresh - salt water interfaces, water table and clay layers. Gravity, magnetic and seismic methods cannot supply accurate information in some of these areas and may cause erroneous depth estimates.

Availability
Superintendent of Documents, U.S. Gov't. Printing Office, Wash. D.C. 20402, Stock Number 2401-0253

REFERENCE 77-1

Keywords
Hydrology, Magnetic surveys, Groundwater determination

Technique | Interest Level
Magnetic surveys | 1

Author
Zohdy, A.A.R.; Eaton, G.P.; and Mabey, D.R., 1974, Application of surface geophysics to groundwater investigations: Techniques of Water-resources Investigations of the U.S.G.S., Book 2, Chpt. D1.

Description
Magnetic surveys may be very simple or very complex depending upon the size of the anomaly. Anomalies of large amplitude may be defined with simple instrument and procedures whereas small amplitude anomalies require more complex methods. The two major applications of magnetic surveys to groundwater studies have been the study of magnetic aquifers, mainly basalt, and determination of basement-rock configuration underlying water-bearing sediments. Study of magnetic aquifers involves the identification of rock type and, in some cases, determination of geometry and magnetic properties. The study of basement-rock configuration involves determining depths to the basement surface at several points which may also include determining relief on the basement surface, such as displacement across a fault. Several examples of magnetic surveys are summarized.

Availability
U.S. Gov't. Printing Office, Washington, D.C. 20302, Stock Number: 2401-02543