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NATIONAL RESEARCH COUNCIL
CANADA
ASSOCIATE COMMITTEE ON SOIL AND SNOW MECHANICS

PROCEEDINGS
OF THE
PERMAFROST RESEARCH CONFERENCE
AT THE
BUILDING RESEARCH CENTRE, OTTAWA
MARCH 27, 1958

REPRODUCED

TECHNICAL MEMORANDUM NO. 60

Ottawa
April 1959

JOINT CHAIRMEN OF MEETING

- | | | |
|------------------|---|--|
| Mr. R.F. Legget | - | Chairman,
Associate Committee on
Soil and Snow Mechanics. |
| | - | Director,
Division of Building Research,
National Research Council. |
| Mr. C.L. Merrill | - | Chairman,
Permafrost Subcommittee,
Associate Committee on
Soil and Snow Mechanics. |
| | - | District Administrator,
Department of Northern Affairs
and National Resources,
Fort Smith, N.W.T. |

A list of those present, with affiliations, will
be found at the end of this Report, as Appendix A.

INTRODUCTION

(1) The meeting was opened by Mr. Legget who welcomed those present on behalf of Mr. C.L. Merrill and himself. He explained that the purpose of the meeting was to provide a broad general review of the research work which had been done into permafrost not only in Canada but also in Alaska. It was, therefore, a special pleasure to welcome the American guests present and to note that they included some of those most expert in permafrost knowledge in North America.

(2) Mr. Legget explained for the benefit of the guests the operation of the National Research Council and its several functions. He outlined the work of Associate Committees, under the auspices of one of which this meeting was being held. He then described briefly the work of the eight Research Divisions of the Council, finishing with an outline of the special functions of the Division of Building Research.

(3) One of these is naturally the problem of building in Northern Canada and it is this practical responsibility that has led the Division into its studies of permafrost. In order to assist this work and to serve building research in the North generally, the Division has a Northern Research Station at Norman Wells. Mr. Legget indicated that other scientists would always be welcome at this Station and that he hoped one result of the meeting would be more visitors at this northern outpost of the Division of Building Research.

(4) Finally, Mr. Legget indicated that, even in the practical work of building research, scientific aspects of permafrost had not been forgotten. It was therefore hoped that the day would result in a general review of both practical and fundamental studies of permafrost and associated phenomena, not only in North America, but with some thought to conditions in other countries. It was planned to ask each person present to outline what they knew of permafrost research and to devote the afternoon to a general discussion based on these factual statements.

SUMMARY OF INDIVIDUAL REPORTS

(5) The following notes summarize the statements then made by all of those attending the Conference. Names and affiliations are listed in Appendix A. Wherever possible, references to publications have been indicated, and are listed in Appendix B.

(6) J.A. Pihlainen - reviewed the history of the research program of the Division of Building Research, starting with the survey of buildings in the Mackenzie River Valley during 1950 (a),* and the Division's participation in the 1951 Purdue airphoto investigations in the same region (b). In 1952, the Northern Research Station was established at Norman Wells and its subsequent development was outlined.

(7) G.H. Johnston - explained that one of the first field projects of the Station, started in 1953, was experimental work on drilling and sampling permafrost. This early work was soon applied in the exploratory boring program at old Aklavik (c). He described the site investigation work carried out on the Aklavik survey under the following headings: airphoto interpretation, terrain studies, drilling and sampling. He also discussed briefly the Division's interest in the development of light exploratory drilling equipment and methods for drilling and sampling in perennially frozen ground.

(8) C.L. Merrill - then described the planning of the survey for the new site for the town of Aklavik, with which he had been connected as project leader. He explained how the team had been organized, how the initial examination of aerial photographs was carried out at the Building Research Centre in Ottawa and how this permitted the planning of a very inclusive field survey during the short working season. He outlined the logistics of the operation which were quite unusual in view of the location of the area to be studied and the limitations of transportation. He summarized the field studies at the four selected sites and explained how "East-Three" was finally selected (d).

(9) J.A. Pihlainen - outlined the opportunity that the construction of a completely new town presented for a study of the effects of construction on permafrost and described the details of projects that the Division is now carrying out at East-Three. These include studies of terrain, roads, building foundations, and runways.

(10) R.F. Legget - described one of the earliest investigations of the Division of Building Research in connection with the distribution of permafrost in Canada which was carried out at Uranium City, Saskatchewan. An inquiry had been received from the Department of Natural Resources of the Province of Saskatchewan when the new townsite of Uranium City was being planned. Since its location is on the north shore of Lake Athabasca, it was at first concluded that there could not be permafrost at this site.

* Letters in brackets refer to references listed in Appendix B.

Field studies, however, had shown that there was indeed permafrost in some locations, although relatively shallow in depth, probably not going deeper than 35 feet. Soil temperature measurements had been made in the field. Studies were continued and it was hoped eventually to publish a paper on the findings of this location, since it is so obviously on the southern border of permafrost (e).

(11) H.B. Dickens - outlined the recent reorganization of the Division's northern responsibilities which now encompass the broader field of building in the North in addition to including work on permafrost. Mr. Dickens introduced Mr. P.J. Williams, who had recently joined the staff of the Northern Building Section, with interests in solifluction and patterned ground. He mentioned one project that the Section was currently planning for, concerned with the study of dyke construction at the new Kelsey Generating Station being constructed on the Nelson River in northern Manitoba. He pointed out this was in an area of sporadic permafrost and jointly with Mr. G.H. Johnston and Dr. D.C. Pearce, outlined the problem in some detail.

(12) L.J. Chapman - mentioned the interest of the Ontario Research Foundation in evapotranspiration studies at Norman Wells and drew attention to the importance of these studies in relation to the energy balance in frozen soil (f).

(13) D. Lane - emphasized the engineering problems of airstrip construction in permafrost areas and related this to the need for design criteria with respect to the fill required to prevent degradation of the permafrost in airfield construction. He also mentioned the problems imposed by permafrost on water supply and sewage disposal in the North at the necessary living quarters which always had to be associated with northern airports.

(14) J.K. Fraser - said that the Geographical Branch of the Department of Mines and Technical Surveys has been established for ten years, during which period they had had thirty field parties in the Arctic, involved in regional studies of terrain analysis (g). He said that they had reached the stage when more detailed and continuing work would be carried out in specific locations. He indicated their interest in patterned ground and subsoil conditions and reported that, to facilitate this work, they were considering establishment of a northern research laboratory in the Arctic.

(15) K.A. Linell - reported that the U.S. Army is responsible for all Army and most U.S. Air Force construction in the North. The U.S. Corps of Engineers established the Frost Effects Laboratory in 1944 and the St. Paul Permafrost Division in 1945.

These were consolidated in Boston in 1953 into what is known as the Arctic Construction and Frost Effects Laboratory. The principal interest of the Laboratory is the determination of engineering design criteria for military construction (h). It does not include studies of snow and ice. Mr. Linell said that their studies were carried out in three phases:

- (i) Field investigations of existing structures
- (ii) Field test installations such as the pile studies at Fairbanks
- (iii) Cold room and theoretical studies in the laboratory dealing with thermodynamics and heat flow analysis. In such heat flow studies, they are utilising two analogue computers.

They are measuring ground temperatures at about two hundred locations in Alaska and Greenland. Pile tests at Fairbanks, started in 1953, have pointed out the difficulties of instrumentation and the need for further work on the instrumentation phase. They are studying the effects of radiation and snow cover on the depth of frost penetration as applied to the performance of various structures.

Cold room studies include work on the effect of fine- and coarse-grained materials on frost action. Some twelve to fifteen variables have to be investigated in this phase. Heat flow studies include both theoretical laboratory research and also actual field work. Their studies had to encompass construction in the worst permafrost conditions, since military requirements did not always permit selection of better sites. He suggested that their experience had indicated construction in the Sub-Arctic posed more serious engineering problems than in the Far North.

(16) W.K.W. Baldwin - expressed his pleasure at being at the meeting and stated that Dr. Porsild would have been present but for his absence in Russia. The botanical staff at the National Museum are interested in permafrost as relating to Arctic vegetation. They had no specific studies of permafrost but in connection with Dr. Porsild's work on the flora of the Arctic (i) and his own studies in the lowlands southwest of Hudson Bay (j), they had seen the inter-relation of permafrost and vegetation. He mentioned his interest in Norwegian studies of plant and species communities in relation to such factors as snow cover and frost intensity.

(17) Dr. Y.O. Fortier - reported on studies of permafrost carried out by the Geological Survey of Canada (k). Within ten years, the bedrock geology of the Arctic islands is to be completed and within five years, the mainland geology from the Mackenzie River to Hudson Bay will be completed. He mentioned briefly the work of their Pleistocene Section and also the Engineering Geology Section (formerly the Ground Water Section). They also have a Geochemistry Section which, while not directly concerned with permafrost, may be able to give useful information in permafrost studies.

(18) H.E. Neal - mentioned that at Knob Lake, the Iron Ore Company of Canada have encountered patterned ground on the uplands at elevations of 2,400 to 2,500 feet. They have installed fifteen thermocouples in bore holes. In the mining operation the main problem arises in blasting the frozen ground. Thermocouple readings indicate greatest depth of permafrost to be about 150 feet. He mentioned the difficulty of determining by thermocouple measurement where the ground is frozen, since the ground temperatures are close to 32°F.

(19) Prof. J. Brian Bird - told of the Knob Lake Sub-Arctic Research Station of McGill University where there are normally four or five students, with Professor Ives in charge. The Station is primarily concerned with meteorological work, although many studies of a geomorphological nature are being made (1). Snow banks and the processes occurring in them are an example. The use of the Station by other interested persons is welcomed. Prof. Bird said that he was particularly interested in heat exchange between the air and the ground. He is at present working on a physiography of the Sub-Arctic from the Mackenzie River to Hudson Bay, where studies are being carried out on superficial deposits, that is, limestone and the bouldery upland surface deposits.

(20) A.T. Belcher - described the general interest in permafrost research of the Arctic Institute of North America of which he is the Executive Director. He explained that the Institute is an international organization drawing the members of its Board of Governors equally from Canada and the United States. It maintains a library at its headquarters in Montreal but its main activity, in addition to publishing "ARCTIC", is channelling funds to research workers for research work in the Arctic. Mr. Belcher promised all the assistance that the Arctic Institute could render to the future development of permafrost research in Canada.

(21) Dr. A.L. Washburn - after being specially welcomed by the Chairman, since he had come to the meeting almost immediately following his return from Antarctica, explained that he had become especially interested during recent years in geomorphological studies in the Arctic (m). During the last year or two, he had been working in Greenland (n) and his studies there had aroused his interest in the quantitative aspects of solifluction and mass wasting. He mentioned the correlation of botanical studies under Dr. Hugh Raup with his own studies of frozen ground.

Dr. Washburn next described briefly some of the things he had seen during his recent visit to the Antarctic. In the McMurdo Sound area, there is an absence of snow and ice during some parts of the year. He had noticed that patterned ground seems to be more prevalent on steep slopes in the Antarctic. He proceeded to give some comparative notes between surface evidence of permafrost in the Arctic and the Antarctic.

(22) P.J. Williams - described the studies that he had carried out in Norway into solifluction problems on thawing slopes (o). He mentioned that he had recently joined the Division of Building Research and hoped to carry out similar studies in northern parts of Canada, possibly at Knob Lake.

(23) Dr. J. Ross Mackay - described sporadic permafrost which he had studied in the Mount Garibaldi area of British Columbia in which he had carried out field investigations. He mentioned his special interest in buried organic layers which had been found in permafrost in the northwestern part of Canada (p).

(24) R.A. Hemstock - mentioned the possible use of seismic methods in permafrost and their potential use for investigation, noting that the velocity of sound waves in frozen ground is much higher than in unfrozen ground. He voiced particular interest in the difficulties of overland transportation in permafrost areas. He next described briefly his early studies of permafrost at Norman Wells, N.W.T. (q). He mentioned current interest of the oil companies of Canada in overland transportation problems, especially in muskeg areas, and pointed out that this problem was related also to permafrost conditions, especially near the southern boundary of permafrost. At the Chairman's request, he gave some general details of the extent of bush road construction for current oil exploration in western Canada (r).

(25) M. Fuchsberger - described the work being done by the Snow, Ice and Permafrost Research Establishment of the U.S. Corps of Engineers, explaining that SIPRE had taken over the permafrost

research work which had been started under the U.S. Corps of Engineers, through its St. Paul Divisional Office. This early work had led to the establishment of an experimental research area at Fairbanks, Alaska, and observations were still continuing at this location. Mr. Fuchsberger explained that SIPRE is becoming more concerned with fundamental Arctic problems, especially those involving the use and effects of explosives in frozen ground. They were actively pursuing studies of special drilling methods in permafrost and expect to be carrying out field work in this connection in Alaska in 1958. They will study the use of different media for circulating fluid, such as oil and compressed air and also experiment with different types of bits and core barrels.

Mr. Fuchsberger outlined some of the work on patterned ground which had been carried out by SIPRE in Greenland but added that this project was almost complete. He referred to the early photo interpretation work that had been carried out by staff from Purdue University. He described briefly to the meeting the SIPRE library facilities at Wilmette, Ill., and mentioned the Field Station now located in northern Michigan (s).

(26) D. Boyd and G. Potter - reported jointly for the Meteorological Branch of the Department of Transport, Mr. Boyd being the climatologist seconded by the Department of Transport to the staff of the Division of Building Research. It was explained that the chief interest of the Meteorological Branch in permafrost problems was the correlation of climate with the existence of permafrost. Some studies of this correlation had been made but nothing had been published. Mr. Potter mentioned that his Branch was soon to establish a project for the study of shallow ground temperatures at twenty different locations and that the results so obtained might be of assistance in future permafrost research work.

(27) Dr. R. Spence Taylor - described the studies of patterned ground which he had carried out on behalf of the Snow, Ice and Permafrost Research Establishment and which had been described in the thesis which he had prepared for his doctorate. This work had not been published but he would be glad to make it available to anyone specially interested. He noted that some permafrost had been found in the foothills of the Rocky Mountains in the west of Alberta.

(28) K. Hawkins - explained that the Department of Public Works has a great interest in construction work in the North. It therefore welcomed the opportunity of participating in this meeting. The Department hoped to use every opportunity for studying the effects of construction upon permafrost and the performance of buildings in permafrost areas.

(29) Lt. Col. Scott Lynn - explained that, despite his early interest in permafrost, his duties in the Canadian Army were now somewhat removed from this field so that he had no official connection with any permafrost studies in the Department of National Defence. He was very glad to know that there was in prospect a manual which would deal with construction methods in permafrost areas. The Chairman mentioned Col. Lynn's early work in this field, noting in particular the excellent manual which Col. Lynn had prepared (t) and the efforts that he had made in developing one of the first general maps to show the distribution of permafrost in Canada.

(30) Dr. Andrew Taylor - spoke briefly of his general interest in permafrost and referred to field studies which he had made both in the Arctic and the Antarctic (u).

(31) J. Day - explained that his own interests lay in the development of agriculture in Northern Canada. The first reconnaissance trips in the North for his Department had been made by Dr. A. Leahey, who regretted that he could not be present at the meeting (v)(w). Mr. Day mentioned that some work had been done on the utilization of plant growth as an indicator of permafrost conditions. For example, it was known that birch trees grow on frozen ground but that aspen do not. He reminded the meeting of the experience that should be available regarding field studies of permafrost through work done during the construction and subsequent maintenance of the Hudson Bay Railway.

(32) Dr. R.F. Black - after referring to the studies which he had made for the U.S. Geological Survey in Alaska, explained that he was now studying fossil patterned ground and post-glacial deposits in Wisconsin. He hoped that the interpretation of these features coupled with his previous experience with permafrost would suggest some useful conclusions regarding processes of permafrost formation (x).

(33) Prof. A.D. Misener - explained that he was interested chiefly in heat flow from the earth, which naturally affected permafrost conditions. It had been found that heat flow from the earth in the North was two or three times as much as that measured in southern regions (y). An unusual change in the ground temperature gradient had been observed at a depth of about 120 feet but this could not be regarded as significant until improved methods of measuring actual ground temperatures had been developed. He had found that thermistors were preferable to thermocouples for this purpose.

(34) Dr. N.B. Hutcheon - brought the review of permafrost and its problems to a close by a discussion of the effect of muskeg cover on frozen ground conditions, suggesting that the effect of the muskeg was much more complex than merely acting as an insulating medium. Dr. Hutcheon spoke of possible instrumentation that might be used for determining accurately depth of the active layer, mentioning specifically the possible development of a new type of probe and the application of seismic techniques.

GENERAL DISCUSSION

(35) Following lunch, the meeting turned to a general discussion of permafrost problems in Canada. This covered almost the entire field indicated by the foregoing detailed reports. Although no conclusions were arrived at by the meeting, the following notes give the sense of the discussion and are recorded, not as "conclusions", but as suggestive of the direction in which future permafrost research in Canada may be expected to proceed:

(36) Permafrost Terminology -

It was clear to the meeting that an agreed-upon terminology for permafrost would be a most desirable aid to further work. Mention was made of a start in this direction by American agencies and it was generally hoped that such a project could be completed before permafrost research advanced too far.

(37) Deep Holes in the North -

The possibility that the Division of Building Research might be able to sink a deep hole in the Mackenzie Delta using its permafrost drilling rig was generally welcomed. It seemed clear that, if such a hole could be properly instrumented, it would yield useful information when correlated with records from existing holes at Resolute Bay, Point Barrow, and Thule. The possibility of using dry holes that may be sunk for oil exploration was noted. American guests promised their co-operation if and when such a hole could be put down and it was suggested that useful advice might be obtained from the Waterways Experiment Station of the U.S. Army at Vicksburg, Miss. The exact location of the hole was not discussed but Division of Building Research representatives promised that all interested would be consulted before any final decisions were made.

(38) The Active Layer -

A useful discussion took place regarding the problem of measuring accurately the depth and the formation of the active layer in permafrost areas. It was suggested that possibly a neutron meter might be used in investigating this matter but the consensus seemed to be that it would be desirable to develop, if possible, some simple seismic method of determining the depth to the frozen material. It was clear to the meeting that the problem, although superficially simple, is actually most complex. Correspondingly, it was agreed that thorough study of the matter would be most valuable.

(39) Patterned Ground -

A correspondingly useful discussion took place regarding patterned ground phenomena. It was pointed out that these are linked with the general problem of frost action in soils now being investigated in the Division of Building Research laboratory. Mr. E. Penner described some of his work and Dr. Washburn suggested that the entrainment of fine particles in upward flowing water during the development of ice lenses might possibly be an important factor in the formation of patterned ground. Dr. Mackay mentioned that he had received a grant from the National Research Council for such studies. Dr. Baldwin mentioned the remarkable examples of patterned ground to be found in the Hudson Bay Lowland. Dr. Bird described something of the work being done in this field at the Knob Lake Station of McGill University.

(40) Engineering Problems -

The latter part of the meeting was taken up by a number of references to the engineering problems in permafrost areas recognized by those present. These may be listed as follows:

- (i) the installation of piles as foundation units and the effect of such piles on the thermal regime of the ground.
- (ii) the construction of embankments and other engineering works upon frozen ground and the effect of such structures, such as the embankment at the Kelsey Generating Station, on the thermal regime of the ground.
- (iii) the problem of icing of roads and other routes which may be constructed across frozen ground such as has developed in some sections of the Alaska Highway.

- (iv) the selection of sites for new building installations such as those which have had to be constructed for the DEW Line and the Mid-Canada Line.
- (v) various difficulties associated with solifluction, especially on sloping ground.
- (vi) the effect of freezing upon the properties of and the ease of handling iron ore such as that which is now being mined in the Knob Lake district.
- (vii) the whole question of thermal flow from the ground, its effect on ground stability and upon structures erected on frozen ground.
- (viii) the construction of pavements, not only for roads, but more particularly for large paved areas such as airfields.
- (ix) the general question of soil temperature variation which can be clearly seen to affect a variety of engineering operations.

CONCLUSION OF MEETING

(41) Mr. Legget brought the meeting to a close by expressing the thanks of the Council for the attendance of all those present, special thanks being expressed to the American visitors. Even though the discussions had been so informal, a summary record of the meeting would be prepared when time permitted in relation to summer field work, and this would be circulated to those present.

(42) The meeting had shown clearly the many interests concerned with permafrost research and suggested the desirability of co-ordinating such efforts in Canada through the medium of a sub-committee of the Associate Committee on Soil and Snow Mechanics, following the pattern which had proved so successful in the case of soil mechanics and muskeg. If and when such a sub-committee was organized, one of its early tasks might be the organizing of a public meeting to discuss permafrost problems in Canada, again following the examples in the fields of soil mechanics and muskeg research. The meeting adjourned at 4:30 p.m.

APPENDIX A

LIST OF THOSE PRESENT AT THE PERMAFROST CONFERENCE

MARCH 27, 1958

From the United States

Black, Dr. R.F.	Department of Geology, University of Wisconsin, Madison, Wisconsin.
Fuchsberger, M.	Snow, Ice and Permafrost Research Establishment, U.S. Corps of Engineers, 1215 Washington Avenue, Wilmette, Illinois.
Linell, K.A.	U.S. Corps of Engineers, Arctic Construction and Frost Effects Laboratory, 150 Causeway Street, Boston 14, Mass.
Washburn, Dr. A.L.	Dartmouth College, Hanover, N.H.

From Across Canada

Belcher, T.A.	Arctic Institute of North America, 3485 University Avenue, Montreal, P.Q.
Bird, Prof. J. Brian	Department of Geography, McGill University, Montreal, P.Q.
Chapman, L.J.	Ontario Research Foundation, 43 Queen's Park, Toronto 5, Ontario.
Hemstock, R.A.	Imperial Oil Limited, 300 - 9th Avenue West, Calgary, Alberta.
Mackay, Dr. R.	Department of Geology, University of British Columbia, Vancouver 8, British Columbia.

Merrill, C.L. District Administrator,
Department of Northern Affairs
and National Resources,
Fort Smith, N.W.T.

Misener, Prof. A.D. Department of Physics,
University of Western Ontario,
London, Ontario.

Neal, H.E. Ore Testing and Research Division,
Iron Ore Company of Canada,
Schefferville, P.Q.

Potter, G. Meteorological Division,
Department of Transport,
315 Bloor Street West,
Toronto, Ontario.

Taylor, Dr. R.S. Department of Geology,
University of Alberta,
Edmonton, Alberta.

From Ottawa, Ontario.

Baldwin, Dr. W.K.W. Botanist,
Department of Northern Affairs
and National Resources,
National Museum.

Day, J. Division of Field Husbandry,
Department of Agriculture,
Central Experimental Farm.

Fortier, Dr. Y.O. Department of Mines and
Technical Surveys.

Fraser, Dr. J.K. Department of Mines and
Technical Surveys.

Hawkins, K. Northern Construction Division,
Department of Public Works.

Lane, D.A. Building Construction Division,
Department of Transport.

Lynn, Lt. Col. S. Directorate of Engineer Development,
Department of National Defence.

Taylor, Dr. Andrew Consulting Engineer,
293 Island Park Drive.

From National Research Council
Division of Building Research

Legget, R.F.	Director
Hutcheon, Dr. N.B.	Assistant Director
Boyd, D.	Climatologist
Crawford, C.B.	Soil Mechanics Section
Dickens, H.B.	Northern Building Section
Johnston, G.H.	Northern Building Section
MacFarlane, I.C.	Soil Mechanics Section
Pearce, Dr. D.C.	Building Services Section
Penner, E.	Soil Mechanics Section
Pihlainen, J.A.	Northern Building Section
Williams, P.J.	Northern Building Section

APPENDIX B

REFERENCES CITED IN REPORT

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- (b) Airphoto Pattern reconnaissance of Northwestern Canada, Interim Report, Volumes I and II. Prepared by Joint Highway Research Project, Purdue University for the St. Paul District Corps of Engineers. February 1953.
- (c) Pihlainen, J.A. and G.H. Johnston. Permafrost investigations at Aklavik (drilling and sampling) 1953. (DBR Technical Paper No. 16).
- (d) Merrill, C.L., J.A. Pihlainen and R.F. Legget. The new Aklavik: search for the site. (Submitted for Publication).
- (e) Legget, R.F. Permafrost at Uranium City, Saskatchewan, with notes on the development of the new townsite. A Progress Report June 1955 (DBR Report No. 60).
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- (o) Williams, P.J. Some investigations into solifluction features in Norway. Geographical Journal, Vol. CXXIII, Part I, March 1957, p. 42-58.
- (p) Mackay, J.R. A subsurface organic layer associated with permafrost in the Western Arctic. Geographical Paper No. 18, Geographical Branch, 1958, 21 p.
- (q) Hemstock, R.A. Engineering in permafrost in Canada's Mackenzie Valley. Proceedings of the Second International Conference of Soil Mechanics and Foundation Engineering, Vol. 4, 1948, p. 62-64. Also appears in Associate Committee on Soil and Snow Mechanics, National Research Council, Technical Memorandum No. 13, June 1949.
- (r) Hemstock, R.A. Permafrost problems in oil development in northern Canada. Canadian Mining and Metallurgical Bulletin, Vol. 45, No. 481, May 1952, p. 280-283.
- (s) List of publications. U.S. Army, Snow, Ice and Permafrost Research Establishment, July 1958, 16 p.
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