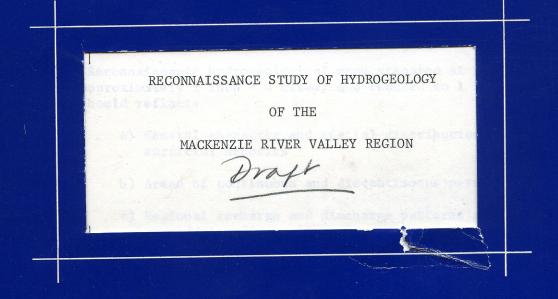
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CONSULTING CIVIL ENGINEERS AND ENGINEERING GEOLOGISTS

Specializing in airphoto interpretation and ground-water studies

RECONNAISSANCE STUDY OF HYDROGEOLOGY

OF THE

MACKENZIE RIVER VALLEY REGION

Prepared for:

Environment Canada Inland Waters Branch Hydrologic Sciences Division Ottawa, Ontario K1A OE7

Attn: Dr. R. L. Harlan
Groundwater Subdivision

April 18, 1972

Prepared by:

J D Mollard and Associates Limited 815 McCallum Hill Building Regina, Saskatchewan

RECONNAISSANCE STUDY OF HYDROGEOLOGY

OF THE

MACKENZIE RIVER VALLEY REGION

TERMS OF REFERENCE

Terms of reference for the present study were set out in a letter dated August 10, 1971, from Mr. W. J. DuBroy, Purchasing Operations Branch, Department of Supply and Services, Ottawa. Dr. R. L. Harlan, Groundwater Subdivision, Inland Branch, Hydrologic Sciences Division, Environment Canada, acted as Project Officer.

In Mr DuBroy's letter, it was stated that the final report on the groundwater investigation should include:

- 1) A summary of relevant groundwater and geologic investigations in the Mackenzie River Region and their findings, and
- 2) Reconnaissance hydrogeological maps prepared at a scale of 1:250,000 (approximately 1 inch = 4 miles) and reduced to 1 inch = 10 miles. These maps should reflect:
 - a) General character and spatial distribution of the surficial deposits
 - b) Areas of continuous and discontinuous permafrost
 - c) Regional recharge and discharge patterns and probable groundwater flow regime
 - d) Location of potentially developable groundwater supplies.

In a letter dated February 8, 1972, Dr. R. L. Harlan noted several additional points that he wanted us to consider in preparing our report on the hydrogeology of the Mackenzie Valley Region. In this connection we were requested to:

1) Select the locations of specific site-areas representative of varying groundwater recharge-discharge regimes in different permafrost environments in order to allow field inspection, limited drilling, and field instrumentation with observation wells and piezometers.

- 2) Comment on the research needs related to northern hydrogeology in general and pipeline construction and operation in particular.
- 3) Comment on possible applications of special-purpose aerial photography and other remote sensors in groundwater investigations in permafrost-affected regions.

SIZE OF AREA STUDIED

Size of study-area was determined firstly by the probable limits of a corridor that are believed to contain all likely transportation routes along the Mackenzie River Valley at the time of study and, secondly, by the need to show sufficient area to allow proper visualization of the regional geologic setting and regional topography and hydrography as they influence groundwater flow systems in permafrost-affected terrain.

The study-area selected is widest at the north, where the band of terrain is nearly 120 miles in width. At its narrow points, the study-area is roughly 70 miles wide, or 35 miles on each side of the Mackenzie River on the average.

Generalized surficial geology maps, surficial hydrogeology, and bedrock hydrogeology maps have been prepared to correspond with all or parts of the following map sheets in the National Topographic Series System (see, also, Fig 25).

Map number in this study	National Topographic S map-sheet number	Series
1	Sibbeston Lake	95 G
2	Fort Simpson	95 H
3	Bulmer Lake	95 I
4		
	Camsell Bend	95 J
5	Root River	95 K
6	Dahadinni River	95 N
7	Wrigley	95 0
8	Blackwater Lake	96 B
9	Fort Norman	96 C
10	Carcajou Canyon	96 D
11	Upper Ramparts River	106 G
12	Sans Sault Rapids	106 H
13	Norman Wells	96 E
14	Mahoney Lake	96 F
15	Lac Belot	96 L
16	Fort Good Hope	106 I
17	Ontaratue	106 J
18	Martin House	106 K
19	Trail River	106 L
20	Fort McPherson	106 M
21	Arctic Red River	106 N
22		
	Travaillant Lake	106 O
23	Canot Lake	106 P

MAIN SOURCES OF REFERENCE AND ASSISTANCE USED IN THE PRESENT STUDY

The following persons were contacted in connection with groundwater studies in permafrost regions. Also mentioned briefly below is the purpose in making each private communication.

Mr. Paul Mascho Department of Public Works Government of Northwest Territories Yellowknife, Northwest Territories

Purpose: Records of drilling and well installation for water supplies at Inuvik, Fort McPherson, Fort Good Hope, Norman Wells, Fort Norman, Wrigley, and Fort Simpson. Communications documented in this report -- see Appendix 'C'.

Mr. Sven Lund Lund Drilling Yellowknife, Northwest Territories

Purpose: Drilling problems and subsurface conditions at drill sites along the Mackenzie River Valley. Communications documented in this report -- see Appendix 'C'.

Mr. Lou Brears
 M. R. Hall Drilling Ltd.
 Regina, Saskatchewan

Purpose: Drilling results in vicinity of Fort Simpson, Northwest Territories. Communications documented in this report -- see Appendix 'C'.

4. Dr.J. Ross Mackay
Department of Geography
University of British Columbia

Purpose: Water-quality data pertaining to the Mackenzie River.

Dr. Mackay's water-quality studies concerned the mixing of Liard and Great Bear River waters with those of the Mackenzie River (see Appendix 'H').

5. Mr. John Piart, Surveyor Federal Department of Public Works Edmonton, Alberta

Purpose: To determine the location of springs along the banks of Mackenzie River Valley since Mr Piart has spent nearly 20 summers on the river. Mr Piart had observed no springs that were not already mentioned in Brandon's paper.

6. Dr. Owen L. Hughes, Dr. Nat W. Rutter, Dr. Jim A. Code, Dr. Pavel Kurfurst, Dr. Ralph M.S. Isaacs, Dr. Don K. Norris, Dr. Chris Yorath Geological Survey of Canada in Calgary and Ottawa

Purpose: Surficial and bedrock geology of the Mackenzie River Valley Region. The several communications from these people were helpful in preparing the surficial geology and bedrock hydrogeology maps.

7. Mr. Steve Zoltai and Dr. Colin Crampton
Northern Forestry Research Laboratory, Edmonton,
and

Dr. J. Stan Rowe Department of Plant Ecology University of Saskatchewan Saskatoon

Purpose: Hydrology of peatlands in the discontinuous permafrost zone.

See Appendix 'D' on measurements of thermokarst lakes and research on the geohydrology of peatlands.

- 8. a) Dr. Charles Slaughter
 Water Resources Division
 Department of Interior
 Anchorage, Alaska
 - b) Mr. Don Morris Water Resources Division Department of Interior Anchorage, Alaska
 - c) Dr. Bob Carlson Institute of Water Resources University of Alaska College, Alaska
 - d) Dr. John R. Williams U. S. Geological Survey Boston, Mass.
 - e) Dr. Charles E. Sloan Groundwater Geologist Anchorage, Alaska

Purpose of enquiries: Groundwater publications and groundwater research in permafrost regions. See
Appendix 'H', dealing with literature digest. Several references obtained from the above persons.

 Mr. Leo V. Brandon Regional Manager Department of Indian Affairs and Northern Development P. O. Box 1767 Whitehorse, Yukon Territories

Purpose: Past studies of groundwater in the Yukon and Northwest Territories. See section documenting private communication -- Appendix 'C'.

10. Mr. J. L. Jenness Sidney River, Nova Scotia

Purpose: Report on drilling of water wells at Norman Wells, Northwest Territories. Referred to other sources of assistance.

11. Messrs. Stewart W. Reeder, Officer-in-charge, Western Water Quality Region, and Paul Fee, in Calgary and Dave R. Silliphant in Regina Water Quality Division Inland Waters Branch

- 12. Dr. L. Dennis Delorme and Dr. Robert O. Van Everdingen Groundwater Subdivision, Hydrologic Sciences Division Western Research Section Inland Waters Branch Environment Canada
- 13. Mr. J. N. Stein, Biologist
 Pollution Control Section, Resource Development
 Department of the Environment
 Fisheries Service
 Winnipeg

Purpose: Water-quality studies and analyses in the Mackenzie River Valley Region. See section on water-quality characteristics -- Appendix 'A.'

14. a) Mr. Rudy W. Klaubert, Ottawa and

Environment Canada

b) Mrs. V. Hewson, Calgary Oil and Gas Land & Exploration Section Oil and Gas Division Northern Economic Development Branch Ottawa and Calgary, respectively

Purpose: Publications and reports giving data based on oil-well drilling along the Mackenzie River Valley. See Appendix 'B' giving extracts from relevant data in oil-company geological reports filed with the Oil and Gas Division, Northern Economic Development Branch, Department of Indian Affairs and Northern Development, Calgary.

15. 1) Dr. Wayne Pettapiece, Pedologist Soil Research Institute
Canada Department of Agriculture Edmonton

Purpose: Groundwater chemistry of surface waters, Sans Sault Rapids to Fort McPherson region. Reported verbally that chemistry of collected surface waters indicated they are essentially rainfall and snowmelt in origin. Dr. Pettapiece ran about 50 specific conductivity tests on waters in peatland ponds. The values commonly ranged from 50 to 100 with an extreme low of 35 to 40 and with only one sample over 200 micromhos/cm.

2) Mr Orest Tokarsky, Hydrogeologist Alberta Research Council

Purpose: Groundwater analyses in northern Alberta (see Fig 23).

3) Dr. Brian Hitchon Alberta Research Council

Purpose: Water chemistry studies of northern regions.

4) Drs. George Ozoray and Joe Toth Alberta Research Council

Purpose: Peatland hydrogeology in permafrost-affected terrain. See section on geohydrology of peatlands and Fig 23. Private communications with all five members of the Alberta Research Council.

16. 1) Dr. Les Lavkulich, Pedologist University of British Columbia Vancouver, British Columbia

Purpose: Soils in vicinity of Fort Simpson.

2) Mr. John H. Day, Pedologist Soils Research Institute Research Branch Canada Department of Agriculture

Purpose: Soils along the Mackenzie River Valley. Communications useful in reconnaissance mapping of surficial geology.

- 17. 1) Mr. Robert W. May, District Engineer, Calgary
 - 2) Mr. Kelt F. Davies, Area Engineer, Calgary
 - 3) Mr. Walter N. Nemanishen, Study Engineer, Calgary
 - 4) Mr. E. Dave Fowler, Officer-in-charge, Fort Smith, Northwest Territories Environment Canada Water Survey of Canada

Inland Waters Branch

Purpose: Streamflow data, riverbed erosion, water-quality data. See Appendix 'A.'

The following available reports and maps were consulted during preparation of this report and accompanying maps:

- 1. The Development of Sedimentary Basins in Western and Arctic Canada (1969), by P. A. Ziegler, Alberta Society of Petroleum Geologists, Calgary.
- 2. Regional Devonian Geology and Oil and Gas Possibilities, Upper Mackenzie River Area (1971), by James Law, Bull. of Can. Pet. Geol. Vol. 19, No. 2.
- 3. Facies and Faunal Relations at Edge of Early Mid-Devonian Carbonate Shelf South Nahanni River Area, N W T (1971), by J.P.A. Noble and R.D. Ferguson, Bulletin of Can. Pet. Geol. Vol. 19, No. 3.
- 4. Reconnaissance Geology, Southern Great Bear Plain, District of Columbia (1971), G S C Paper 71-11, by H.R. Balkwill.
- 5. The Lower Mackenzie River Area, N W T and Yukon (1954), G S C Memoir 273 and maps by G. S. Hume, Pub. No. 2513.
- 6. Virginia Falls and Sibbeston Lake Map-Area, Northwest Territories, G S C Paper 60-19, by R.J.W. Douglas and D. K. Norris; reprinted in 1970 along with Maps 22-1960 and 23-1960.
- 7. Camsell Bend and Root River Map-Areas, District of Mackenzie,
 Northwest Territories, Report, 2 maps, 2 figures, G S C Paper
 61-13 by R.J.W. Douglas and D.K. Norris; reprinted in 1970
 along with Maps 22-1961 and 23-1961.
- 8. Subsurface geology, Lower Mackenzie River and Anderson River Area, District of Mackenzie (1969), G S C Paper 68-25 by E.J. Tassonyi; includes report and 11 figures on stratigraphic correlation charts, cross-sections, and comparative formation nomenclature for the Upper and Lower Mackenzie River Valley Regions.
- 9. Hydrographic maps of the Mackenzie River from Mile 200 at Fort Simpson to the delta of the Mackenzie River (1970); published by the Canadian Hydrographic Service, Marine Sciences Branch, Department of Energy, Mines and Resources, Ottawa.
- 10. Glacial Lake McConnell and the Surficial Geology of Parts of Slave River and Redstone Map-Areas, District of Mackenzie (1965), G S C Bull. 122 and map, by B. G. Craig.

- 11. Reconnaissance Surficial Geology Maps, on open file at the Geological Survey of Canada, and covering the following National Topographic Series map sheets:
 - Dr. O. L. Hughes: 106 H, 106 G, 96 C, 96 D, 96 E (scale: 1 inch = 4 miles)
 - Dr. R. J. Fulton: 106 O, 96 E, 96 F, 96 L, 106 I, 106 J, 106 P (scale: 1 inch = 4 miles)
 - Drs. O. L. Hughes and
 V. N. Rampton: 106 M, 106 N, 106 L, 106 K, 106 E,
 106 F
 (scale: 1 inch = 4 miles)
- 12. Ground-Water Hydrology and Water Supply in the District of Mackenzie, Yukon Territory and Adjoining Parts of British Columbia (1965), by L. V. Brandon, G S C Paper 64-39; report includes 25 figures, 3 plates, and 14 tables.
- 13. Soils of the Upper Mackenzie River Area, N W T, by J. H. Day, Soils Research Institute, Central Experimental Farm, Research Branch, Canada Department of Agriculture, 1966.
- 14. Reconnaissance Soil Survey of the Liard River Valley, N W T, by J. H. Day, Soils Research Institute, Central Experimental Farm, Research Branch, Canada Department of Agriculture, 1966.
- 15. Schedules of Wells, Northwest Territories and Yukon Territory, Federal Department of Indian Affairs, Ottawa, Ontario.

The following scales of contact aerial photographs and mosaics were used to help prepare the accompanying generalized surficial-geology map, surficial-hydrogeology map, and bedrock-hydrogeology map:

- Contact aerial photographs at an approximate scale of 1 inch = 3300 feet; obtained from the National Air Photo Library in Ottawa.
- 2. Two flight lines of colour infrared (false colour) aerial photographs that were taken along both sides of the Mackenzie River between Sans Sault Rapids and Fort Simpson, with a short gap in the photography near Wrigley; at an approximate scale of 1 inch = 2000 feet.
- 3. Aerial mosaics at scales varying from 1 inch = 4.5 miles to 1 inch = 6.5 miles, approximately.
- 4. Aerial mosaics at a scale of 1 inch = 2 miles, approximately.

As part of this reconnaissance groundwater study, an attempt was made to obtain available literature containing findings relevant to groundwater and related geological investigations in the Mackenzie River Valley Region of the Northwest Territories. Altogether over 80 literature references were obtained, and abstracts of this literature are summarized in an accompanying Appendix.

APPROACH TO PREPARATION OF THE ACCOMPANYING MAPS

All available non-confidential geological maps and reports that could be procured were used as a framework and guide to initial mapping of the surficial and bedrock geology. These were used in conjunction with the study of contact aerial photographs and aerial mosaics at one or more scales. An attempt was made to examine the more critical areas stereoscopically using 1 inch = 3300-foot contact aerial photographs. Generally such areas are located within what is likely to be the main transportation corridor, which follows lowland regions. On the other hand, highland watersheds likely to contribute groundwater recharge were also studied -- mainly in aerial mosaics and on regional geological maps. In other words, a large proportion of the 50,000 square mile study-area was examined only in mosaics and geological maps and not in stereoscopic pairs of contact airphotos.

Because of the significance of heat#flow and groundwater movement in areas underlain by widespread permafrost in the discontinuous permafrost zone, colour infrared photographs were purchased and studied because they frequently disclose the stress effects of plants that are affected by shallow active layer, fire, disease, insect, and other adverse environmental factors. It was suspected that the type, stature, density, and stressed condition of vegetation would all indicate something useful about the nature of local heat-flow patterns and prevailing groundwater flow regime.

Thus the three sets of maps that were produced from office study alone include material that was either traced or interpreted from different scales and types of geological, soil, and hydrographic maps as well as aerial mosaics, conventional panchromatic airphotos, and colour-infrared photography.

REGIONAL AND LOCAL CLIMATIC AND PERMAFROST CONDITIONS Regional conditions (see Fig 24)

a) From Fort McPherson to Sans Sault Rapids across the Peel Plateau and Peel Plain

The mean daily temperature in January is less than -20°F and in April is
between 10° and 15°F. There are about four months of growing season and an
average of five months when the temperature is 0°F or lower. Mean annual number
of days of measurable snowfall is 60; and of measurable precipitation, 110 days.
Mean annual total snowfall is 50 inches, about the same as Calgary and Edmonton.
Mean date of the last snow cover of 1 inch or more is May 20. One can expect
about 220 days with 1 inch or more of snow cover and a maximum snow cover of
around 30 inches. Mean annual precipitation ranges between 11 and 13 inches.
Permafrost may be 300 to 400 ft thick in vicinity of Fort McPherson depending
on the site tested.

The "Permafrost Map of Canada" shows the Peel Plateau and Peel Plain to be underlain by widespread permafrost in the discontinuous permafrost zone. However, in virtually all areas covered by Sphagnum moss,lichen (Cladonia spp.), and black spruce thepermafrost is continuous north of the 20°F mean annual air isotherm -- i.e., between Fort McPherson and Sans Sault Rapids. Yet wherever there has been long-standing water on the ground surface -- seemingly regardless of the size or depth of the water body -- the permafrost appears to have degraded to depths of 20 to 40 feet or greater. The great preponderance of these unfrozen "windows" are located below elevation 400 feet in what is believed to be essentially continuous permafrost.

b) From Sans Sault Rapids to Fort Simpson along the Mackenzie Plains

The January mean daily temperature varies from $-20^{\circ}F$ at Sans Sault Rapids to $-15^{\circ}F$ at Fort Simpson. Mean daily temperatures in April vary from $15^{\circ}F$ at the north end to $25^{\circ}F$ at the south end of the Mackenzie Plains.

Mean annual number of days with a minimum temperature of 0°F or lower varies from about 150 days at the north to about 110 days at the south end. The mean annual length of growing season varies from 120 days in vicinity of Sans Sault Rapids to 140 days in vicinity of Fort Simpson. Mean annual number of days with measurable snowfall is 60 and with measurable precipitation is 100. Mean annual total snowfall is 50 inches and mean annual total precipitation is about 12 inches. Mean date of the last snow cover of 1 inch or more is May 20 at Sans Sault Rapids and is April 30 at Fort Simpson. Mean annual maximum depth of snow is 30 inches and this is quite consistent along the entire Mackenzie Plains. But the mean annual number of days with snow cover of 1 inch or more varies from 230 days at the north end to 180 days in the south end of the Mackenzie Plains (see Fig 24).

The Mackenzie Plains lie between the 20° and 25°F mean air isotherms. This region is underlain by widespread permafrost in the northern part of the discontinuous permafrost zone. The mean annual air temperature at Norman Wells is 20.8°F and at Fort Simpson it is 20°F. Recorded mean annual ground temperatures at 0 to 5 feet at Fort Simpson range from 33.2° to 35.4°F. At a depth of 50 to 100 feet at Norman Wells, recorded mean annual ground temperatures range from 26° to 28.5°F. Permafrost thickness is 150 to 200 feet at Norman Wells and some 40 feet thick at Fort Simpson.

The active layer is 3 to 5 feet at Norman Wells and 5 and 10 feet at Fort Simpson. Under well insulated, densely shaded sites, however, the active layer

is probably less than 2 or 3 feet thick — even at the very southern end of the Mackenzie Plains. But below more open stands of taller trees at this latitude, the active layer may be 4 to 6 feet below ground surface. Because there appears to be a noticeable change in tree species and canopy density in vicinity of Norman Wells, one might expect that permafrost is more widespread and that ground temperatures are colder between Sans Sault Rapids and Norman Wells than they are south of Norman Wells along the Mackenzie River Valley. Local conditions

a few feet of ground surface below vegetation-covered lowland areas between

Fort McPherson and Fort Simpson, many localized areas and situations occur where

permafrost either exists at several tens of feet or is absent altogether. It

is important that these special terrain situations be recognized, for they are

likely to have a bearing on groundwater hydrology. In fact, the three attached

maps must be studied with these terrain settings in mind because most of the

degraded permafrost sites are too small in size to show at map scales of 1 inch =

4 miles and 1 inch = 10 miles, respectively. These local topographic, drainage,

geologic, and vegetation settings are listed below. While the list below may

not be complete it is believed to represent the common occurrences of locally

depressed permafrost tables and places where permafrost is absent within essentially

continuous permafrost. These "windows" in the permafrost table may be sites

of localized groundwater recharge or discharge. They may function as both recharge

Although essentially continuous permafrost exists within several inches to

The following local hydrogeologic sites and settings correlate with significantly depressed permafrost tables and/or absence of permafrost (i.e., windows):

and discharge areas at different times of the year, depending on their local

hydrologic setting within the regional groundwater flow system.

- 1. Large lakes and active river channels (Figs 1, 2, 4, 5, 6, 7, 11).
- 2. A variety of thermokarst depressions including small thaw lakes, pools, and ponds. They are characterized by standing still water or by sluggish surface and slow groundwater movement (Figs 3, 4, 5, 7, 8, 9, 10).
- 3. A variety of wetlands underlain by peat and supporting characteristic vegetation (peatlands), such as a) patterned fens and b) small windows and collapse scars in bogs that have a water table at or locally above ground surface for most of the year, the latter usually occurring in extensive peat plateaus. (The terms "wetland," "peatland," "fen," and "bog" are defined later in this report.)
- 4. Temporarily abandoned straight and serpentine back channels on floodplains, oxbow lakes, and active distributary channels on alluvial fans and deltas (Figs 4, 5, 6, 12).
- 5. Periodically inundated river point-bars that repeatedly receive a cover of fresh silt sediment and which support tall large-diameter white spruce and balsam poplar along with dense willow thickets (see Figs 1 and 5).
- 6. South-facing sunny slopes that receive unusually large amounts of solar radiation (see Fig 6).
- 7. Naturally or artificially cleared areas where the vegetation and underlying peat layer has been removed and the permafrost table has degraded. Special situations are landslides and sloughing banks, especially on southfacing and west-facing slopes, active lateral river erosion and undercutting of south- and west-facing valley banks, and roads, trails and village areas where the vegetation and peat have been stripped and the underlying mineral soil left exposed to the sun (see Figs 4 and 6).
- 8. Well-drained elevated landforms underlain by thick, clean and permeable granular materials. In these landscapes the water table is deep and the soils may be dry frozen on shaded slopes and unfrozen on sunny slopes (Figs 5 and 11).
- 9. Exposed bedrock outcrop with no soil or vegetation cover and mainly in topographic situations that receive large solar radiation inputs (Fig 1).

REGIONAL AND LOCAL GROUNDWATER RECHARGE AND DISCHARGE SYSTEMS

Regional groundwater flow systems along the Mackenzie River Valley are controlled mainly by large-scale topographic features like mountains, plateaus, lowland plains, and major river valleys (see Figs 14, 15, 16). On a regional scale the groundwater table is believed to mirror the surface topography, with highlands being dominantly groundwater recharge areas and lowlands and major river valleys being dominantly groundwater discharge areas (see Appendix 'A': water quality vs streamflow). Even though this seems to be the general situation, there can be exceptions. For example, at certain times of the year some of the rivers may discharge into underlying aquifers and build up groundwater mounds beneath the river — the groundwater flowing away from the river channel rather than toward it (private communication from Dr. C. E. Sloan, concerning rivers in central Alaska). Any such groundwater mounding beneath large rivers usually builds in summer. In order to verify this condition in specific cases, piezometers measuring deep groundwater level measurements are necessary.

Examination of chemical analyses of river water quality reveals that the total dissolved solids increases with decreases in surface runoff — that is, at times of the year when there is a proportionately greater contribution of groundwater containing higher concentrations of dissolved minerals. At least this seems to be the situation in the case of the Peel. Arctic Red, Liard, and other rivers (see Appendix 'A' on water quality versus streamflow). It may be that the lower reaches of the major tributaries are recharged by groundwater whereas parts of the Mackenzie River lose water to deep alluvial strata. One might suspect that part of a river channel may receive groundwater recharge whereas other parts of the same river channel may recharge aquifers beneath them — and these recharge/discharge regions may operate seasonally. We consider such possibilities should be carefully studied. A proper understanding of them necessitates further research.

Based on our present knowledge it seems that major streams arising in the Mackenzie Mountains are fed primarily by rainfall and snowmelt runoff whereas streams and major rivers crossing the North Slope of Alaska and the Yukon are fed partly by thermal springs in watersheds along the north side of the Brooks Range and British Mountains — well within the continuous permafrost zone (private communication from Dr Peter McCart, fish biologist). Thermal springs feeding rivers crossing the Arctic North Slope probably have a deep-seated bedrock source along lines of tectonic weakness; and while similar thermal springs exist along the Mackenzie River Valley (Mountain River at lat. 65°25'; long. 129°10'; Old Fort Island and Roche-qui-a-1'Eau) they seem to be much less common in occurrence. Temperature of groundwater at the spring at Roche-qui-Trempe-a-1'Eau, N W T, is 70° - 80°F; and temperature of the spring at Old Fort Island, 53°F (after L. V.Brandon). (See,also, "Groundwater in Canada," Economic Geology Report No. 24, edited by I.C. Brown (1967), pp. 185, 186.)

On a more local basis it is likely that there is little or no direct recharge to groundwater from areas underlying sloping fine-grained surficial deposits (lacustrine, till) that are relatively dry and support a tree cover of stunted black spruce and a ground cover of Sphagnum moss and/or Cladonia, the latter mainly reindeer lichen (Figs 2 and 10). This accounts for most of the mineral soil upland and extensive peat plateaus, excluding in the latter small unfrozen windows and collapse scars and, for the most part, elongate channelways occupied by ribbed fen. Within these latter isolated wet places in peatlands it is difficult to predict confidently if (and at what time of year) these unfrozen "windows" in the permafrost act as groundwater recharge or groundwater discharge areas. Nor is it perfectly clear just how such localized groundwater flow regimes change with changes in latitude and altitude between Fort McPherson and Fort Simpson. These are matters of continuing hydrogeological and geohydrological research in peatlands occurring within the discontinuous permafrost zone.

From inspection of conventional (panchromatic) aerial photography, black-and-white infrared aerial photography, false-colour (colour-infrared) aerial photography, and colour-infrared ground photography it would seem that the following hydrogeological relationships exist; but they must still be tested under varying field conditions:

- 1. There seems to be a noteworthy change in groundwater hydrology, natural vegetation, and peat depth in comparable geological, topographic, and drainage conditions between the continuous permafrost zone on the Peel Plateau west of Fort McPherson (say above about elevation 1500) and the discontinuous permafrost zone on the Peel Plain east of Fort McPherson.
- 2. On the Peel Plain and Peel Plateau between Fort McPherson and Sans Sault Rapids, many of the thermokarst features (lakes and ponds) seem to be reducing in size as a result of "new" permafrost aggradation around their shorelines. Thus there is probably very little groundwater recharge from standing water in the unfrozen "windows," the chimmeylike cylindrical walls of which are likely to be nearly vertical (private communication from S. Zoltai and testhole logs and probings studied by the authors). Computations of changes in lake widths were made in area in vicinity of Fig 2 but results were inconclusive (see Appendix 'D').
- 3. The northern portion of the Mackenzie Plains extending from Sans Sault Rapids to roughly Great Bear River appears to be a transitional zone in which thawing (permafrost degradation) is occurring around some thermokarst features and freezing (formation of "new" permafrost) is occurring around others. In fact, we believe that segments of shoreline on a single thaw pond or lake (thermokarst depression) may be melting (naturally retrograding) whereas other segments of the shoreline on the same lake or pond may be stable (in equilibrium) or possibly freezing (permafrost aggradation). See Fig 3. These suspicions should be checked by properly controlled field research programs.
- 4. The southern portion of the Mackenzie Plains, especially around and south of Fort Simpson, seems to be situated in an area where the thermokarst features are actively melting (permafrost degradation). In this region, groundwater probably moves from ribbed fens and small treeless near-circular collapse scars out into unfrozen peat beneath frozen peat plateaus and underlying unfrozen mineral soils. Groundwaters within ribbed fens probably moves downslope within subsurface fen peat (see Figs 8 and 9).

Because it is possible that unfrozen "collapse scars" in frozen peat plateaus (ice-rich peat) and unfrozen ribbed fens surrounded by sloping frozen impermeable peatlands (Fig 9) may be either local groundwater discharge or recharge sites it will be necessary to install nests of piezometers in and around these thermokarst features and measure them several times a year to determine what

is taking place seasonally and with regional changes in latitude and altitude. The groundwater and heat flow measurements should also be related to physical characteristics of the thermokarst feature.

Current differences of opinion as to the origin of thermokarst features may be related to seasonal effects, to latitude and altitude, soil texture and slope position and in turn to geohydrologic flow systems within the widespread permafrost region within the discontinuous permafrost zone (see section in this report dealing with suggested research).

EXPLANATION OF THE SURFICIAL GEOLOGY MAP AND LEGEND

The generalized surficial geology map shows the inferred origin, compositional character, and spatial distribution of surficial geological deposits. These deposits are shown on maps having scales of 1 inch = 4 miles and 1 inch = 10 miles, respectively, as well as on twenty-three (23) 8½-inch x 11-inch-sized pages at the back of the report. The assembled map sheets at scale 1 inch = 10 miles and covering the entire study-area are contained in a map pouch at the back of the report. This composite map has been made by splicing together the individual 1 inch = 10 mile maps. Four sets of the composite surficial geology maps have been coloured.

The mode and environment of sediment deposition as well as the lithology and stratigraphy of the various map-units may be inferred from the legend shown on each map-sheet. There are advantages to this kind of presentation for the hydrogeologist. For example, the map reader studying an area of ground moraine (G) exhibiting streamlined ice-flow features will know that if the till is derived from shale (from reference to the bedrock hydrogeology map) the subsoils will be homogeneous, exhibit very low permeability, and will act as an aquiclude or aquitard even though the till sheet may contain randomly distributed inclusions of sand and gravel. The map-unit G frequently contains patches of lacustrine silty clay and clayey silt to elevation 600 ft and even above this elevation locally. However, if well-defined glacially streamlined forms were apparent in the photos, we mapped the area as ground moraine. In

the complex mapped as N it is not possible to separate the islands of till and surrounding waterlaid sand, silt and clay.

Lacustrine deposits (L) will be massive to varved and laminated, and even though predominately silt and clay in texture these sediments will contain some fine sand seams and partings. Map-unit L is finely layered, represents deposition in a deeper offshore glacial-lake environment, and generally occupies poorly-drained lowland areas. On slopes in former lakebed areas there are few thermokarst depressions; but in poorly drained flatlands they are numerous. These sediments do not contain commercial quantities of groundwater. They are finely stratified, exhibit low permeability, are only unfrozen where there is standing water (thermokarst lakes), and generally contain high and highly variable ice contents. Silty and clayey deposits in L interfinger with lake-deltaic sand and silt, marked D, and in many places it is difficult, if possible, to define the boundary between L and D without extensive testhole drilling and detailed sample inspection.

Surficial deposits marked F are subject to flooding, sudden changes in erosion and deposition, are permeable, and potentially may store large quantities of good quality groundwater. Glaciofluvial terraces and outwash plains appear to be dominantly sandy rather than gravelly.

The various surficial geology map-units have been grouped hydrogeologically (see following section). Descriptions below each map-unit allow such grouping.

Fig 25 is a key map showing the locations of individual $8\frac{1}{2}$ " x 11" surficial geology maps numbered 1 to 23, respectively.

EXPLANATION OF THE SURFICIAL HYDROGEOLOGY MAP AND LEGEND

An attempt has been made to group the surficial geology map-units into hydrogeology map-units, still retaining the symbols used on the surficial geology map showing the general character and distribution of the surficial deposits. Grouping is based on anticipated quality and quantity of groundwater that might be developed from individual wells assuming that a proper exploration, testing and well construction program is carried out. The inference here is that the groundwater investigation be carried out by a competent water-well driller under the supervision of an experienced hydrogeologist. The surficial hydrogeology map is intended as a groundwater probability map of surficial deposits and a guide to groundwater exploration.

It was considered desirable to retain the map-unit boundaries shown on the surficial geology map in preparing the surficial hydrogeology map because certain landforms that have been grouped together may, upon detailed drilling and well testing in the field, prove to yield slightly better quantities and qualities of water than other units in the group. The more promising map-units can then be easily recognized and separated out.

Because the number of tested water supplies are extremely limited for such a large area -- less than a dozen small sites in an area extending over 50,000 square miles -- the estimates given for probable maximum yields and anticipated water quality must of necessity be largely "educated guestimates." It should also be stressed that the safe yield figures given are not absolute maximum values but probable maximum estimates. Moreover, the figures do not refer to the safe yield from a well drilled at random in a particular map-unit, but rather to the results of a properly organized and conducted test-drilling program supervised by an experienced, competent hydrogeologist after he has first carried out a

detailed field-geological reconnaissance of the study-area. This definition of hydrogeological map-units applies to groundwater exploration in the Mackenzie River Valley as it does to groundwater investigations on the Prairies, where as many as a dozen or more testholes may be drilled at carefully preselected test sites before the site for a permanent well site is discovered, and a well is installed, developed, and put into production. It is important that the reader interpret the hydrogeological map in this context.

Data in the map legend suggest that the best water-supply prospects are located in wide braided rivers — especially below river bars on the active floodplain, beneath frequently inundated abandoned back channels on the inactive flood plain, and below wooded islands surrounded by coarse sand and gravel channel-lag alluvial deposits. This map—unit is marked F. The next best commercial sources of groundwater are probably large freshwater lakes (marked "lakes"), followed by sand and gravel outwash and terrace deposits where these glaciofluvial deposits are sufficiently low—lying to be recharged from lakes and rivers. These deposits are marked 0 and T. They are considered to be better groundwater prospects than the group of landforms that include A, E, D, W, I and C. These coarser—textured deposits are likely to yield small water supplies only where they happen to be unfrozen — for example, a) below south-facing slopes, b) around the margins of large water bodies such as lakes, creeks, and rivers, and c) where the landforms are traversed frequently by surface runoff.

Springs should always be examined in the field; we were able to detect a very limited number only owing to the small scale of aerial photography examined. Twenty-three individual $8\frac{1}{2}$ " x 11" surficial hydrogeology maps follow the surficial geology maps and occupy similar areas (see key map in Fig 25).

EXPLANATION OF THE BEDROCK HYDROGEOLOGY MAPS AND LEGEND

An attempt was made to show generalized groups of sedimentary rock map-units considered significant in understanding regional groundwater flow systems (see Appendices 'F' and 'G'). The twenty-three 8½" x 11" maps at the end of this report contain information on 1) general topographic position of the various map-units, 2) tectonic history as related to degree of structural disturbance and thus secondary (fracture) porosity and permeability, 3) lithology and stratigraphy as they effect the primary (intergranular) permeability of varying strata (e.g., shale versus sandstone), 4) environment of sedimentary deposition as this affects rock type and quality of water that has migrated through these bedrock sediments. For example, one may anticipate sulphate waters in gypsiferous marine shale formations and carbonate-anhydrite formations, sulphate and chloride waters in formations that contain gypsum, anhydrite, and salt beds; and hard bicarbonate waters in dolomite and limestone beds. Better quality waters may occur in broken, brecciated, and basal zones in fresh-water (i.e., non-marine) sandstones having favorable secondary (fracture) porosity and permeability resulting from Early Tertiary crustal disturbances. Anticlinal and synclinal folds and major thrust faults are associated with Late Laramide orogeny, which occurred some 50 million years ago.

The bedrock hydrogeology map at a scale of 1 inch = 10 miles shows

1) contours, 2) different ages of the various sedimentary-rock formations,

3) lithology (rock type) and stratigraphy (layering and interbedding) of the

map-units to the extent possible at a scale of 1 inch = 10 miles, 4) environment

of sediment deposition such as mainly marine or mainly non-marine, 5) regional

bedrock structures (synclines, anticlines, and major thrust faults).

The more productive aquifers are likely to occur in thick uncemented Tertiary sand and gravel (T); in thicker and coarser non-marine Cretaceous basal sandstone beds; in more fractured and porous zones in Devonian sandstone, limestone and dolomite rocks marked Dm, Dmk, Dmh, Dmbr, Duu, Duk, Dutt; and in Ordovician, Silurian and Cambrian strata shown as OS and OSk, Gca. Of these the Bear Rock, Nahanni and Kee Scarp Formations are probably the most permeable bedrock formations in the Mackenzie Valley region and they therefore represent potentially major bedrock aquifers. They show up on the bedrock hydrogeology maps as Dmbr, Dm, Dmk and Dmki map-units.

If the groundwaters have travelled very far through these rocks the water quality is likely to be poor (generally high in sulphates -- i.e., "sulphurous"), for it is believed that there is a close association between water quality and rock type through which the groundwater has migrated. Likewise, there appears to be a close correlation between water quality and magnitude of streamflow. Water quality and water temperature in bedrock also varies markedly with depth.

The occurrence of large flows of saline water in deep bedrock zones, as evidenced by deep boreholes, large saline springs, and well-developed sinkholes suggest groundwater movement within the deeper bedrock strata. One of the largest areas of widespread solution of carbonate and evaporite rocks occurs east of Fort Good Hope and north of Norman Wells. Here widespread collapse structures have been reported. Whether or not these structures result from the widespread solution of anhydrite beneath less soluble dolomite beds of the Bear Rock Formation is unknown; but this possibility is suspected by the writers (see, also, the location of sinkholes on the surficial-geology map).

Generally poor quality groundwater may be expected from the following formations K1, K1f, K, Dur, Dus; Dm (sulphate waters), Dmc (sulphate waters), Dmki (sulphate waters), Dmbr (sulphate waters, locally), OSk (sulphate waters) and 6cs (sulphate and/or chloride waters).

GROUNDWATER DEVELOPMENT PROBLEMS

The following potential problems should be considered in exploring, testing, and developing groundwater sources along the Mackenzie River Valley (see, also, Appendix 'C' summarizing private communications from Mascho, Lund, and Brandon as well as literature digest, Appendix 'H'):

- 1. Much of the groundwater found in fine-grained glacial-drift deposits and in the underlying bedrock is likely to contain high sulphate, chloride, iron, and manganese contents.
- 2. Groundwater quality is likely to vary seasonally with stream discharge and also with the chemical composition of the rock strata through which the groundwaters have moved (see Figs 28 and 29).
- 3. Small groundwater sources located remote from major rivers and lakes may be depeted with continued pumpage because sources of recharge may be cut off by permafrost barriers.
- 4. Groundwater qualities may also deteriorate with continued usage and are likely to vary widely with depth below ground surface.
- 5. Freezing of water wells may be a problem in some localities; and in certain cases it may be necessary to operate the well continuously or, alternatively, install some suitable built-in heating unit.
- 6. Because suprapermafrost aquifers often tend to be thin and occur in local and regional topographic depressions, contamination of groundwater can be a serious problem.
- 7. Icing conditions at faults and joint fissures, at the contacts of water-bearing fissured sandstone or porous limestone over shale, and at springs at the contact of sand and gravel beds over clay, till or shale can build up ice mounds a few to several tens of feet thick. These ice mounds may even interfere with the normal pattern of surface runoff because of delayed runoff associated with temporary storage above the ice dams (private communication from Dr Charles Slaughter, Alaska).
- 8. The better groundwater prospects are located along major rivers that experience highly variable discharge and consequent shifting of the river channel along with excessive, and destructive, lateral erosion and temporary deep channel bed degradation. Probable maximum depth of riverbed degradation during high floods is therefore an important consideration in the installation of Ranney-type collector systems. Considerable ingenuity will be required in the design of collectors and wells to tap water in unfrozen deep sand and gravel strata and yet not be removed and destroyed by river erosion (private communications from L. V. Brandon, C.E. Sloan, and Appendix 'H').

SELECTION OF POSSIBLE SITES FOR HEAT-FLOW AND GROUNDWATER FLOW RESEARCH

Sites selected for the measurement of heat flow and groundwater movement are best illustrated by means of selected panchromatic and colour infrared aerial photographs. In this way, specific terrain features can be identified and discussed. If research programs are implemented, it will very likely be necessary to install nests of piezometers at different depths below ground level and at different distances back from the margins of thermokarst features as well as within some of these features. Accordingly, the recognition of these terrain features in airphotos is important.

Alternate site-areas for prospective groundwater research are shown on Figures 1 to 13 accompanying this report. Listed below are the figure numbers, hydrogeological research objectives, and general locations (see, also, Appendix 'B').

- $\underline{\text{Fig 1.}}$ Determine size, shape, and hydrology of aquifer (thawed area) in sand dune (S) at Old Fort Point south of Fort Norman; on the east bank of the Mackenzie River. Panchromatic airphoto. Observe details of stratigraphy in exposed river bank and strata from which water is seeping.
- $\underline{\text{Fig 2}}$. Determine local heat-flow regime and possible permafrost aggradation around lakes on Peel Plain west of Arctic Red River. Panchromatic airphotos. Explain dark rims around these lakes.
- Fig 3. Measure suspected localized permafrost melting (pink vegetation) around thaw lakes in vicinity of Wrigley. Colour-infrared airphoto.
- $\underline{\text{Fig 4}}$. Monitor heat flow and water movement and water/ice relationships on and around islands in the Mackenzie River near Norman Wells. Colour-infrared airphoto. Correlate man-induced effects and changes in the hydrology of the active layer.
- $\underline{\text{Fig 5}}$. Relate groundwater movement and heat flow to vegetation type, soil and rock type, hydrographic and topographic settings. Along the Lower Carcajou River east of West Mountain. Colour-infrared airphoto.
- $\underline{\mathrm{Fig}}$ 6. Compare groundwater regime and active-layer thickness in east-facing versus west-facing slopes and effects of differences in solar radiation on permafrost thawing, plant stress, and slope instability (at white arrow). This area is also located on the Carcajou River Valley, west of the Canol Road. Colour-infrared airphoto.

- Figs 7, 8 and 9. Study the hydrology of 1) patterned (ribbed) fens (unfrozen), 2) wooded peat plateaus (frozen), and 3) small treeless collapse scars (unfrozen) in the peat plateaus. Figs 7 and 8 are colour-infrared airphotos and Fig 9 is a panchromatic airphoto. Research carried out here in summer of 1971 by Dr. L. Lavkulik, (pedologist), Dr. J. S. Rowe (plant ecologist), Prof. J. Murray (hydrologist), Dr. N. Rutter (geologist), Dr. C. Crampton (forest ecologist).
- $\underline{\text{Fig 10}}$. Determine possible reduction in size of thaw ponds having floating vegetation -- i.e., new permafrost around pond margins. Plot water content profiles for possible "new" versus "old" permafrost around these thermokarst features. Panchromatic airphoto. (Check with S. Zoltai about his research and findings in this field of endeavor.)
- $\underline{\text{Fig 11.}}$ Attempt to measure differences in heat flow in warmer elevated sands (dunes) and colder low-lying finer soils north of Norman Wells. Colour-infrared airphoto.
- <u>Fig 12</u>. Examine Sammon's Creek for places where river water goes underground and reappears as springs and check water quality vs source rock (Dmki?) and stream discharge.
- $\underline{\text{Fig }13}$. Attempt to correlate chemistry of river water with chemistry of possible seeps and springs along valley walls opposite sinkholes and thus source rock (Middle Devonian carbonate and evaporite beds).

In addition to these prospective research studies of heat-flow and groundwater movement in different permafrost environments, we believe it would be useful to try and monitor regional groundwater flow systems. In this connection we suggest you consider installing piezometers along a long crossvalley (transverse) profile in an attempt to disclose regional groundwater flow patterns at Roche-qui-Trempe-a-1'eau or at Oscar Creek. An alternate piezometric profile might be considered at Norman Wells, extending from the limestone upland to the bars in the Mackenzie River -- either north or south of Bosworth Creek (see Fig 4).

Several alternate site-areas are shown and described in captions to the figures because it is difficult for us to know which research project or site-area you may favor for economic, research, or logistics reasons.

SOME NORTHERN HYDROGEOLOGY RESEARCH NEEDS

A Groundwater contribution to streamflow and its relation to fish biology

In subarctic and arctic regions the contribution of groundwater to streamflow is important in northern ecology as well as Arctic geotechnology. Based on our regional studies of aerial photographs and of relevant map and report data we believe that groundwater discharge into streams is probably relatively more important ecologically in the continuous permafrost zone than in the discontinuous permafrost zone. The major north-flowing rivers across the Arctic North Slope in Alaska and Yukon seem to be fed to a significantly much larger extent by thermal springs in the Brooks Range and British Mountains — important in the spawning of certain species of fish, as Arctic Char — than is the case with streams originating in the Mackenzie Mountains and Franklin Mountains, where runoff from rainfall and snowmelt is likely to be a more important factor.

Springs are reported on islands in the Mackenzie River as well as such creeks and rivers as the Rabbitskin, Saline, Sammon's, Mountain, North Redstone, Great Bear, Beavertail and Mountain.

Research that is slanted toward the relative importance of groundwater flow in northern (arctic and subarctic) ecology (plants and animals including fishes) would likely prove useful.

B Relation of permafrost degradation/aggradation to latitude, altitude, changing climate

As may be noted elsewhere in this report, we suspect that permafrost may be presently aggrading on the Peel Plain and Peel Plateau, may be presently degrading from some point south of Norman Wells to Fort McMurray in northern Alberta, and may be nearly at equilibrium or may be either aggrading or degrading or both around the same thermokarst feature in vicinity of Norman Wells to Wrigley, or thereabouts. If these suspicions are correct, are these naturally-occurring present-day changes related not only to latitude, as indicated above, but also

to altitude, to changes in climate, and to hydrogeological factors.

From a research standpoint there is need to obtain and analyze data on water-content vs depth profiles and groundwater-movement profiles and groundwater chemistry using suitably located piezometer nests in places where the permafrost is actively building (aggrading, building "new" ice) and where it is actively melting (degrading, only "old" ice).

Attempts to measure change in size of thermokarst features over a 20-year period proved inconclusive using medium-scale photography (see section of report dealing with such measurements -- i.e., Appendix 'D'.)

C Geometry of thermokarst features

We have long felt that thermokarst-feature size, depth, shape, shoreline configuration and presence or absence of floating, submergent, and emergent pond vegetation -- among other terrain features identifiable in airphotos -- should be systematically studied, possibly using computers, to determine which of these recognizable "indicators" yields the most useful data on type of mineral sediment in the substrate, b) age of the thermokarst features, c) relevant details of geomorphic/climatic/vegetational history, d) volume of subsurface ice present in different localities, e) existing thermal condition of the permafrost or the possibility of changing thermal conditions in the ground from locality to locality, f) relation of heat flow and movement and chemistry of groundwater. See thermokarst features on Figs 1 (upland), 2, 3 (white arrows), 4 (white arrow), 5 (S), 7 (white specks in PP), 8 (center of colour infrared photo), 9 (CS), 10 (W), 11 (upland north of Mackenzie River).

To oversimplify, one might suspect that In the continuous permafrost zone:

- 1) Large, deep thaw depressions indicate a thick ice-rich silt layer over gravel or bedrock, and
- 2) Large, shallow thaw depressions indicate thin ice-rich silt layer of gravel or bedrock;

In the discontinuous permafrost zone:

- 1) Dark ground-cover vegetation rims around the shoreline of thaw ponds suggests permafrost aggradation (especially in vicinity of Arctic Red River)
- 2) Sharply outlined water basins and raw crumbling peat banks suggest active melting under existing natural (not man-induced) conditions.
- D Relation of erosion/sedimentation history within the Mackenzie River channel to groundwater flow and chemistry

Deep boreholes for oil exploration disclose 200 to 300 feet of waterlaid silt and very fine sand in the vicinity of Camsell Bend. This would appear to place the base of waterlaid sediments in the Mackenzie Valley floodplain near Camsell Bend at or below elevation 90, which is well below the level of shale bedrock crossing the Mackenzie riverbed at Sans Sault Rapids. At Sans Sault Rapids, the shale in the riverbed occurs around elevation 140, or some 50 feet above the elevation of the base of waterlaid sediments (alluvial or lacustrine?) at Camsell Bend, even though Sans Sault Rapids is situated over 300 miles downstream in the same valley. Thus, one may ask: Did the bedrock in the riverbed at Sans Sault Rapids act as a plug in the regional groundwater flow system? Also, does this plug, if that is what it is, affect the chemistry of groundwater in the deeper alluvial sediments in the Mackenzie River bed. One would suspect that there has been very little change in the Mackenzie River channel since deglaciation some 10,000 to 13,000 years ago. (This view has also been mentioned by Dr. N.W. Rutter, G S C, Calgary — private communication.)

We feel this is a possible groundwater research problem.

E Back flooding in lower reaches of major tributaries

Backflooding could very seriously and substantially affect the availability of usable groundwater supplies beneath floodplains along the lower 1 to 10 miles of major tributaries to the Mackenzie River. The length of reach affected depends on the gradient of the tributaries and the fact that the Mackenzie at flood discharge may back up water to depths of 20 to 30 feet in these tributaries and induce deposition of clay, silt, and very fine sand in their lower reaches. Ordinarily one would expect to find sand and gravel at the mouths of such highenergy rivers as the Mountain and Keele. But stratified fine sand and silt occur below the active flood plain at the mouth of the Mountain River (personal observation). Not only does such backflooding into low-gradient tributaries affect groundwater yield but also, possibly, the chemistry of groundwater in sections of tributary river valleys that may eventually be crossed by main transportation routes (highways, railways, pipelines). Thus the location of high-yielding water wells in the floodplains of these tributaries must consider backflooding effects.

F Relation of northern hydrogeology to pipeline construction and operation

There is little question that groundwater movement and pore-water pressure dissipation will have a marked bearing on the stability of a buried warm-oil pipeline in steeply sloping ice-rich fine-grained soils. An analysis of this problem must consider the interaction of many parameters over a period of time. The problem very likely necessitates computer programming and analysis in order to determine probable magnitude of the effects. The stability of a pipeline and surrounding ground is affected by many factors: density and permeability of the soil surrounding a warm-oil pipeline (both relate to rate of pore-water dissipation); ice content and its distribution in the subsurface; shape, size, and temperature of the heat source; various thermal characteristics and

properties of the permafrost-affected soil; hydraulic gradients; strength of the unfrozen soil; and degree of slope (topography) across which a warm-oil pipeline traverses. There may be other factors that should be considered in computer programming and analysis. This type of heat flow and groundwater movement research could be useful as follow-up work on early studies undertaken by Dr Arthur Lachenbruch of the U S Geological Survey at Menlo Park, California, and recent computer studies by Dr. Norbert R. Morgenstern, Department of Civil Engineering, University of Alberta, Edmonton.

Because of the complexity of these interacting variables and the possible variations in procedures of constructing and operating warm-oil and chilled-gas pipelines, which are not fully known to us, we hesitate to comment on the hydrologic implications of construction and operation of a pipeline except to note that the implications require careful examination and study and attempts must be made to properly evaluate them.

G Geohydrology of northern peatlands

The role that groundwater hydrology and chemistry play in the formation of wetland fens versus deep ice-rich bogs along the Mackenzie Valley and south to Cold Lake, Alberta, is in our opinion a most important facet of northern hydrogeological research.

Terms frequently used by peatland ecologists should perhaps be defined because they may be unfamiliar to geologists, groundwater hydrologists, and engineers.

A WETLAND is an ecosystem having its water table near the surface of the main root system of plants growing in it. A PEATLAND is a wetland with substantial deposits of partially decomposed vegetal matter (i.e., peat). Peatland types can be differentiated into two main types -- fens and bogs -- according to the source of water supply promoting their accumulation.

In Dictionary of Ecology, Herbert C. Hanson defines a FEN as a tract of low marshy ground containing peat that is relatively rich in mineral salts, alkaline in reaction, often situated around or near freshwater lakes, and is vegetationally distinct from bogs. Hanson defines a BOG as an undrained or imperfectly drained depressional area that is covered with sedges and shrubs (Ericaeous, especially) and sphagnum mosses, is poor in mineral nutrients, is typically underlain by sphagnum peat, and is often dotted with islets of open water. Groundwater in bogs is usually highly acidic in reaction (pH of 3 to 4) whereas groundwater in fens is alkaline in reaction (pH over 7). Thus fens are usually found overlying calcareous parent materials (soils and rocks).

Ivan MacFarlane in "Muskeg Engineering Handbook" University of Toronto Press, 1969, describes FEN MUSKEG as peatland that is supplied by water previously in contact with mineral soil. He says that sloping fens are subject to groundwater flowing through the system — as distinguished from bogs that are fed by precipitation that has been effectively isolated from passage through the mineral substrate. Bog vegetation is thus OMBROTROPHIC (i.e., rainfall-nourished) and fen vegetation is MINEROTROPHIC (i.e., mineral-nourished), or fed by water in contact with mineral materials.

In the Mackenzie Valley region the distinction between fens and bogs is significant in groundwater studies because fens and bogs are widespread, vary substantially in ice content (permafrost), and because the surface and near-surface water movement is different in each type of peatland, even though intergradations and transitions commonly occur between them. Thus, one may speak of "true fens" and "true bogs" and of transitions between them.

It appears that true fens tend to be wet; to form in elongate channelways; to develop on gentle slopes that follow concave slopes, and the lower parts of

slopes and watersheds; to have pH values in the range of 7 or higher; to be relatively rich in nutrients, and particularly Ca and Mg ions; to support Hypnum mosses, sedges (Carex spp.), aquatic marsh grasses, dwarf or swamp birch, willows, and tamarack; to be generally unfrozen; and to be fed by groundwater that has migrated through a basic mineral substrate. On the other hand, true bogs (e.g., peat plateaus) tend to be relatively dry on the surface; to develop on convex surfaces near or at the crest of water-table divides; to have a pH of 3.5 to 4.5; be relatively poor in nutrients and especially in Ca and Mg ions; to be covered by a limited range of vegetation (Sphagnaceae, Ericaceae, and Black spruce), such as Sphagnum mosses, Reindeer lichen (Cladonia spp.), heath shrubs (Labrador tea, bog rosemary, leatherleaf, bog laurel, various blueberries, crowberries, cranberries and cowberries), and by stunted ragged spindly black spruce; to be generally frozen, often containing high ice contents; to be fed directly by rainfall and snowmelt -- not by groundwater that has passed through the mineral substrate; to be underlain by acidic rather than basic soil and rock types. In most peatlands the ground surface corresponds closely with the water table. Moreover, infertile sites (peat plateaus) tend to accumulate peat more rapidly and harbour more ground ice than fertile sites (e.g., fens).

A fundamental research question concerns whether collapse scars (windows) in peat plateaus originate from differences in vegetation, snow cover and standing water on ground surface or melting from below by artesian groundwaters.

The role of surface and groundwater hydrology and chemistry is fundamental to a proper understanding of northern peatlands and to the highly varying occurrence of permafrost in them. Probably no one has done more research in this field, as it applies to the Mackenzie Valley, than Mr. Steve Zoltai, presently at Edmonton. Other Canadian research workers interested in the hydrology and evolution of permafrost-affected northern peatlands are Dr. J. S. Rowe, Saskatoon, Dr. Wayne Pettapiece, Edmonton, Dr. Charles Tarnocai and Jean Thie,

pedologists with the Canada Department of Agriculture, Research Station,

Pedology Unit, in Winnipeg, and Dr Roger J. E.Brown, Permafrost Section,

Division of Building Research, National Research Council, Ottawa. Mr. Zoltai

has worked mainly on peatland stratigraphy and related vegetation; and it might

be useful to supplement Mr. Zoltai's studies with detailed chemical profiles of

the groundwater as well as with profiles of groundwater flow as determined from

nests of precisely located piezometers.

SPECIAL-PURPOSE AIRBORNE REMOTE SENSING DEVICES

We feel that a balanced approach to the use of remote sensors is highly desirable in studying northern permafrost terrain. We believe the broader aspects of surficial geology, soils, vegetation, and permafrost are best interpreted from conventional (panchromatic) aerial photography, beginning with photos at a scale of 1 inch = 8000 feet and finally interpreting photos at a scale of 1 inch = 1000 feet to 1 inch = 2000 feet. Once this has been done, it is believed that refinements in data sensing can probably be achieved by recourse to airborne electrical-resistivity surveys (lateral and vertical variations in terrain resistivity), thermal-infrared imagery (the affecting variables of which must be carefully controlled and known for meaningful interpretation), black-and-white infrared photography(for surface drainage delineation and separation of deciduous and coniferous vegetation), and colour-infrared photography (for identification of plant stress that might be imposed by a thin active layer as well as other stress-generating factors). When the active layer is 4- to 6-feet thick, most trees are little if at all affected by underlying permafrost. We would like to have seen the colour-infrared aerial photography extended from Sans Sault Rapids to Fort McPherson and on northward into the continuous permafrost zone.

Thermal infrared, microwave radiometry, and side-looking radar imagery are all limited because of the high frequencies employed and limited depth penetration -- of the order of a few centimeters only.

Although each sensor has a contribution to make, we feel that colour-infrared aerial photography is perhaps as good as any, except possibly resistivity surveys. We have very little knowledge of electrical-resistivity surveys, some experimental work of which has been carried out by Barringer Research Limited of Rexdale, Ontario.

Main applications of the more esoteric remote sensors include the 1) detection of possible environmental relationships that might not otherwise be suspected;

2) selection of better field test sites, inasmuch as the sensors will shed light on what to look for in the field, where to sample in the field, and on preferable locations of piezometers and other field instrumentation.

SUMMARY OF FINDINGS AND RECOMMENDATIONS

- 1. We have prepared a) reconnaissance surficial geology, b) surficial hydrogeology, and c) bedrock hydrogeology maps covering some 50,000 square miles along the Mackenzie River Valley Region, beginning at a point south of Fort Simpson to and ending just north of Fort McPherson, Northwest Territories. The entire map-area is located within the widespread permafrost region of the discontinuous permafrost zone according to the "Permafrost Map of Canada." These maps have been explained in the body of this report.
- 2. We have described anticipated regional and local groundwater recharge and discharge systems and patterns in this region of widespread permafrost in the discontinuous permafrost zone and have sketched inferred regional groundwater flow systems.

- 3. We have pointed out a number of alternate research sites and types of northern hydrogeological research problems that we feel should be carefully considered. We recommend that the suggested alternate sites and research projects be carefully examined because, owing to possible limited available time and budget controls, it may be that only a few test sites and research projects can be undertaken. We have tried to include a wide enough range of site-areas and research projects to provide for reasonable selection. These are summarized in Appendix 'E'.
- 4. There is a paucity of existing data, sufficiently relevant and complete, to allow clearcut hydrogeological relationships to be disclosed for every situation that may be encountered along the Mackenzie River Valley. Gaps in existing data which would otherwise make the data more useful to the research hydrogeologist and geohydrologist could we believe be obtained at relatively little extra time and expense. In this connection we recommend that the Ground-Water Subdivision of Inland Waters explore the possibilities and costs of:
- 1) Getting the Fisheries Branch to include a complete chemical analysis of river and lake waters. The present method of chemical analyses and reporting does not allow a proper cation and anion balance to be made in order to confidently identify groundwater recharge/discharge areas and relationships.
- 2) Getting oil companies running drill-stem tests to collect water samples and run chemical analyses on all boreholes drilled. Temperatures of groundwater in boreholes could also be readily reported and these would be useful.

The existing partial data is frustrating because it is difficult to do more than suspect groundwater recharge-discharge relationships. A set of regulations suitable for the Fisheries Branch and for oil companies alike would go a long way toward overcoming this situation, and add a great deal to the knowledge of northern hydrogeology at comparatively little extra cost.

5. Appendices A, B, C, D, E, and H are included to document our own studies as well as sources of assistance. These include evidences of groundwater discharge, Appendix 'A'; extracts from oil-company geological reports, Appendix 'B'; documentation of private communications concerning water-well drilling, water supply and groundwater development problems, Appendix 'C'; attempts to measure thermokarst aggradation and degradation, Appendix 'D'; potential research site-areas and projects, Appendix 'E'; digest of relevant literature, Appendix 'H'; and one set of xerox copies of water quality data sent to us by Dr L. D. Delorme, Appendix 'I'; and use of drillstem tests to interpret the groundwater flow system, Appendix 'J'.

Groundwater recharge appears to be occurring in highlands with local groundwater discharge in lowlands -- notably the Mackenzie River and its main tributaries. Major differences in permeability between rock strata result in exceptions to this general flow regime (see Appendix 'J').

Deeper-lying groundwater and groundwater in older formations generally show higher total dissolved solids, even though there are exceptions, as indicated on the stratigraphic cross-section D-D' near Wrigley (Fig 21) and cross-section B-B' near the Arctic Red River (Fig 19).

Localized groundwater discharge into creeks and rivers is suggested by an increase in specific conductivity of the water during low-flow periods (see Appendix 'A'). Yet surface waters in ponds and lakes on the Peel Plain, Peel Plateau, and Mackenzie Plain appear to have very low dissolved mineral contents -- generally much lower than lakes and ponds on the Prairies.

CHEMICAL ANALYSES OF WATER SUPPLIES AT FORT GOOD HOPE AND FORT NORMAN, NORTHWEST TERRITORIES

1. Fort Good Hope. Water taken from spring in esker on October 30, 1970.

Constituent	Concentration in ppm
Total hardness as	
CaCO3	215
Phenolphthalein alkalinity	
as CaCO ₂	ni1
Total alkalinity as CaCO3	218
Iron	1.6
Manganese	<0.01
Nitrate nitrogen	0.22
Free-ammonia nitrogen	0.01
Calcium	58
Magnesium	17
Sodium	6
Bicarbonate	131
Carbonate	ni1
Sulphate	4
Chloride	313
Fluoride	0.09
Total dissolved solids	252
pH	7.75

2. Fort Good Hope. Water taken from the water-distribution system on October 2, 1970.

Constituent	ppm
Total dissolved solids	284
Hardness (as CaCO ₃)	198
Iron	0.02
Total alkalinity (as CaCO ₂)	224
Sulphate	122
Chloride	2

3. Fort Norman. Water taken from village well.

Constituent	Concentration in ppm after 12 hrs pumping at 18 Igpm in July 1970	Concentration in ppm after 24 hrs pumping at 18 Igpm in July 1970	Concentration in ppm on January 5, 1971
m 1 1 1 1 1			
Total dissolved		4.000	
solids	1209	1250	1316
Nitrate	0.09	0.10	0.10
Iron	3.3	5.4	1.20
Phenolphthalein			
alkalinity as CaC	0, 0	0	0
Total alkalinity as	3		
CaCO ₂	110	112	118
Total hardness as			
CaCO ₃	218	226	220
Calcium	57	64	62
Magnesium	18	16	11
Sodium and potassiu	m 363	366	398
Carbonate	0	0	0
Bicarbonate	134	137	71
Sulphate	132	135	132
Chloride	539	546	573
рН	8.0	7.9	7.8
			,

APPENDIX 'D'

MEASUREMENTS OF DIAMETERS OF LAKES IN
THERMOKARST AREAS SHOWN ON 1950 AND 1970 AERIAL PHOTOGRAPHY
VICINITY OF MARTIN HOUSE AND FORT SIMPSON, NORTHWEST TERRITORIES

Previous airphoto studies in Alaska, in the Mackenzie River Valley region, in northern Ontario, Manitoba, Saskatchewan, Alberta and British Columbia by the authors indicates that permafrost aggradation might be taking place at a measurable rate in some areas whereas permafrost degradation is occurring in other places. This suspicion was given support in talks with Mr Steve Zoltai, Federal Forestry Research Laboratory in Edmonton on October 14, 1971 and in Ottawa on February 3, 1972. Perhaps the best available evidence is that collected by Jean Thie, Department of Soil Science, University of Manitoba and documented in his report titled "Air Photo Analysis and Description of Surficial Deposits of An Area North of Lake Winnipeg, with Special Reference to the Occurrence and Melting of Permafrost," April, 1971.

A number of measurements of lake diameters were made on medium-scale aerial photography showing two selected locations along the Mackenzie River Valley in an attempt to determine whether or not permafrost has been discernibly aggrading or discernibly degrading over the past 20 years. The northern site selected is located in essentially continuous permafrost near Martin House on the Arctic Red River; the second site chosen is located in discontinuous permafrost near Fort Simpson. In carrying out this office-based study we followed the procedure outlined briefly below:

- 1. We acquired two sets of aerial photographs showing the same area but taken 20 years apart -- 1950 and 1970.
- 2. Then, as accurately as possible, we established the scale of each set of airphotos. We made certain that the difference in airphoto scales was accurate by measuring the distance between identical points on the airphotos taken in 1950 and 1970 and then calculating the precise scale of one set of airphotos using the other set as a measurement base.

- 3. We selected lakes in ice-rich peatlands; the lakes were about one-half mile in diameter and located in ice-rich peatland. We then attempted to make accurate measurements of changes in the shorelines of the lakes over a period of 20 years.
- 4. We selected several sections across the lakes. Sections across were taken at places where lake shorelines were especially well defined, so that precise measurements could be made.
- 5. Then, at the selected sections, we accurately measured the widths of lakes on the 1950 and 1970 airphotos. This was done using the 1/50-inch divisions on a standard engineer's scale and the airphotos which varied in scale from about 1 inch = 2000 ft to 1 inch = 3300 ft.

Locations of features selected for the determination of possible permafrost aggradation and degradation were as follows:

In the continuous permafrost zone: Latitude: 66°55'

Longitude: 133°25'

Location: Martin House, Northwest

Territories

National Topographic Series mapsheet:

106 K

In the discontinuous permafrost zone: Latitude: 61°45'

Longitude: 121^o08'

Location: Across the Liard River from

the Fort Simpson Airport

National Topographic Series mapsheet:

95 H.

Based on several comparative airphoto measurements at each location we reached the conclusion that it was not possible to confidently establish whether or not thermokarst has been actively aggrading or degrading over the last 20 years. Some lake shorelines showed small increases over the 20-year period whereas others showed a similar magnitude of decreases in lake diameter. Lake diameters ranged between 2000 feet and 3000 feet in width. Differences in lake width measured on the 1950 and 1970 airphotos fell in the 25-foot to 75-foot range. Therefore, it appears that field measurements and observations are needed in order to establish reliable permafrost aggradation and degradation trends within the selected study-areas. Scales of two sets of aerial photography were 1 inch =

2000 feet and 1 inch = 3000 feet, approximately; and it is felt that these scales are too small to permit detection of small amounts of lake shoreline advance or retreat. Scales of 1 inch = 1000 feet to 1500 feet would have been much better. Also, at larger scales it would be preferable to measure windows or thermokarst collapse scars rather than lakes occupying ice-rich peatland.

Regarding Jean Thie's work north of Lake Winnipeg in Manitoba, in his conclusions he states:

- 1) Most permafrost in this area could have been formed after 600 years BP and before 200 years BP (= before the present time).
- 2) Collapsing in peat plateaus from melting of permafrost has been going on for some time from 200 to 100 years BP, and most likely from 120 to 100 years BP, when the climate is alleged to have begun to ameliorate.
- 3) Some segments of the rims of the collapse scars showed melting rates as low as 0 to 5 meters in 20 years. The rate of degradation on collapse scars 100 to 750 meters across ranged from 5 to 20 meters in 20 years; and collapse scars smaller than 100 meters across showed collapsing rates of 15 to 30 meters in 20 years.

Mr Jean Thie discusses the melting of permafrost bodies within the southern fringe of the discontinuous permafrost zone of Manitoba (equivalent to south of a line through Fort Simpson and Camsell Bend, Northwest Territories) in relation to relatively alleged recent changes in climate. In this connection, it is instructive to study Dr. J. Terasmae's graph showing changes in climate during the Wisconsin glaciation and postglacial time as related to present average annual temperature (see Fig 30). Mr. Thie's studies would lead one to speculate that the greatest chance of detecting permafrost degradation using comparative low-level airphotos (say 20 years apart) would occur in peatlands located south of about Camsell Bend in the Northwest Territories.

APPENDIX 'E'

ALTERNATE HYDROGEOLOGIC RESEARCH SITE-AREAS AND RESEARCH PROJECTS

Fig No. 1

Geographic location

Old Fort Point

Relevant airphoto

A11973 -- 210

National Topographic Map Series (1 inch = 4 miles)

96 C

Latitude

64⁰40'

Longitude

124°50'

Potential northern hydrogeological heat-flow and ground-water movement research project

To determine the nature of ground-water flow at the spring emanating from sand dune in vicinity of Old Fort Point.

Fig No. 2

Geographic location

West of the Arctic Red River near Martin House

Relevant airphoto

A12702 -- 56

National Topographic Map Series (1 inch = 4 miles)

106 K

Latitude

66^o55'

Longitude

133°25'

Potential northern hydrogeological heat-flow and ground-water movement research project

To determine potential rate of advance of permafrost face around margin of large lakes on the Peel Plain.

Fig No. 3

Geographic location

Hodgson Creek near Wrigley

Relevant airphoto

A30366 -- 201

National Topographic Map Series (1 inch = 4 miles)

95 0

Latitude

63°20'

Longitude

123°30'

Potential northern hydrogeological heat-flow and ground-water movement research project

To determine the rate of retreat of permafrost around the margins of thermokarst ponds.

Fig No. 4

Geographic location

Norman Wells and Bear Island

Relevant airphoto

A30366 -- 114

National Topographic Map Series (1 inch = 4 miles)

96 E

Latitude

65⁰15'

Longitude

126°50'

Potential northern hydrogeological heat-flow and ground-water movement research project

To determine pattern of heat flow and ground-water movement in permafrost-affected islands in the Mackenzie River channel.

Fig No. 5

Geographic location

Carcajou River east of West Mountain

Relevant airphoto

A30366 -- 13

National Topographic Map Series (1 inch = 4 miles)

106 H

Latitude

65°30'

Longitude

128^o15'

Potential northern hydrogeological heat-flow and ground-water movement research project

To monitor heat flow and ground-water movement in relation to different types of vegetation, soil and rock type, and drainage/topographic settings.

Fig No. 6

Geographic location

Carcajou River near the old Canol road

Relevant airphoto

A30366 -- 35

National Topographic Map Series (1 inch = 4 miles)

96 E

Latitude

65°10'

Longitude

127°20'

Potential northern hydrogeological heat-flow and ground-water movement research project

To determine the relation existing among slope aspect, solar radiation, ground-water regimes and slope stability in south-facing versus north-facing river banks.

Fig No. 7

Geographic location

South Blackwater River on the east side of the Mackenzie River

Relevant airphoto

A30366 -- 187

National Topographic Map Series (1 inch = 4 miles)

95 0

Latitude

63⁰45'

Longitude

124°00'

Potential northern hydrogeological heat-flow and ground-water movement research project

To determine the geohydrologic aspects of frozen wooded peat plateaus and unfrozen small treeless collapse scars in these peat plateaus.

Fig No. 8

Geographic location

Near Bear Rock, north of Great Bear River

Relevant airphoto

A30366 -- 129

National Topographic Map Series (1 inch = 4 miles)

96 C

Latitude

65⁰05'

Longitude

125°35'

Potential northern hydrogeological heat-flow and ground-water movement research project

To determine the geohydrologic aspects of ribbed fen (e.g., ground-water discharg vs ground-water recharge, or seasonally both).

LIST OF APPENDICES

- Appendix 'A' -- Evidences of groundwater discharge along the Mackenzie River Valley from plots of streamflow and specific conductance of the water
- Appendix 'B' -- Extracts from oil-company geological reports filed with
 Oil & Gas Exploration Section, Northern Economic Development
 Branch, Department of Indian Affairs and Northern Development
- Appendix 'C' -- Documentation of private communications concerning water-well drilling, groundwater supply, and groundwater development problems along the Mackenzie River Valley
- Appendix 'D' -- Comments on attempts to measure permafrost degradation and aggradation around thermokarst features near Martin House on Arctic Red River and Fort Simpson
- Appendix 'E' -- Possible alternate hydrogeological research site-areas and projects
- Appendix 'F' -- Expanded legend used in preparing the generalized bedrock hydrogeology map
- Appendix 'G' -- Abbreviated bedrock hydrogeology legend used on maps
- Appendix 'H' -- Literature digest
- Appendix 'I' -- One set of xerox copies of water quality data forwarded to us by Dr L. D.Delorme and Paul Fee, Groundwater Subdivision, Hydrologic Sciences Division, Western Research Section, Inland Waters Branch, Environment Canada
- Appendix 'J' -- Use of drill-stem tests to interpret the regional groundwater flow system.

APPENDIX 'A'

EVIDENCES OF GROUNDWATER DISCHARGE ALONG THE MACKENZIE VALLEY FROM PLOTS OF STREAMFLOW AND SPECIFIC CONDUCTANCE OF THE WATER

Groundwater discharge into some lakes, creeks, and rivers is suggested by an increase in specific conductance of the water during low-flow periods. Figs 28 and 29 show plots of specific conductance against stream discharge for the Mackenzie River and five tributary rivers to the Mackenzie.

It is worth noting that the quality of water in the more northerly streams is influenced to a smaller degree by the inflow of groundwater, presumably because of thicker and more continuous permafrost the farther north one goes. As an example, the Peel River shows less influence of groundwater inflow than the Liard River (see Fig 28); likewise, the Arctic Red River shows relatively less groundwater inflow than the South Nahanni River (see Fig 29). Chemical analyses of Mackenzie River water samples collected during winter months, when the river flow comes almost entirely from the Great Slave and Great Bear Lakes, show little change in quality. During summer months, however, there is evidence of substantial groundwater inflow. This aspect of the Mackenzie River chemistry was noted in a paper by A.A. Levinson, Brian Hitchon, and S.W. Reeder when they report (see reference below): "The results show, quite surprisingly, that during periods of high discharge the Mackenzie carries more total dissolved solids per unit volume than it does during periods of low discharge." These data strongly suggest that groundwater discharge is retarded by freezing temperatures during winter months. Even though it is evident that further research data and analyses are needed, the data gathered to date seem to indicate that there is substantial regional groundwater movement and that notably less groundwater discharge occurs during the winter months.

The following table shows a comparison of the specific conductance of water samples collected from three creeks in the vicinity of Norman Wells during the period June 25 to October 3, 1971.

Specific conductance in micromhos/cm

Date sampled	Vermilion Creek	Prohibition Creek	Oscar <u>Creek</u>
25/6/71	800	255	
9/7/71	1120	210	
16/7/71			560
25/7/71	450		
1/8/71			535
17/8/71	560	275	
22/8/71	312		
27/8/71			241
3/9/71	880		
11/9/71			382
17/9/71	970		
25/9/71			392
3/10/71	1040		

Vermilion and Prohibition Creeks are approximately six miles apart.

Oscar Creek is located approximately 40 miles downstream of these two creeks on the east side of the Mackenzie River. Vermilion Creek waters show a markedly higher specific conductance than Prohibition Creek, even though in several instances both creeks were sampled on the same days. This comparison suggests greater groundwater discharge along Vermilion Creek and/or the

presence of more readily dissolved gypsum and anhydrite strata in the Bear Rock Formation (<u>see</u> sinkholes adjoining Vermilion Creek on the accompanying surficial-geology maps).

The following three publications were studied and found to be pertinent in our study of water quality in the Mackenzie Valley Region:

- 1) "Groundwater Hydrology and Water Supply in the District of Mackenzie, Yukon Territory, and adjoining parts of British Columbia," Geological Survey of Canada Paper 64-39, by L. V. Brandon.
- 2) "Regional Variations of River Water Composition Resulting from Halite Solution, Mackenzie River Drainage Basin, Canada," by Brian Hitchon, A. A. Levinson, and S. W. Reeder; in Water Resources Research Vol 5, No. 6, Dec. 1969.
- 3) "Major Element Composition of the Mackenzie River at Norman Wells, N.W.T., Canada," Contribution No. 424, Research Council of Alberta, by A. A. Levinson, Brian Hitchon and S.W. Reeder, 1969.

Surface water samples collected from lakes and ponds along the Mackenzie River Valley by Dr. L. D. Delorme show specific conductances generally below 300 micromhos/cm, with the exception of one lake located approximately three miles northeast of Little Chicago (lat. 67°14'; long. 130°10'), which shows a specific conductance in the range of 900 to 1000 micromhos/cm (see, also, page 6, item 15 under Pettapiece). The low specific conductivity values suggest that there is little groundwater movement into surface ponds because of a deep permafrost layer, which acts as an impermeable boundary.

For comparison purposes the following total dissolved solids values, obtained from the Saskatchewan Water Resources Commission, show mineral concentrations in lake waters in southern Saskatchewan:

	Approximate total
<u>Lake</u>	dissolved solids (ppm)
Last Mountain Lake	2000
Fishing Lakes	1600
Madge Lake	500
Jackfish Lake	2000
Big Quill Lake	42,000
Little Quill Lake	5000 to 8000

Specific conductance of a small pond of snowmelt water in the Kerrobert, Saskatchewan, district approximately one week after spring thawing began was 5000 micromhos/cm. These values are markedly higher than those of surface waters collected in the Mackenzie River Valley Region.

From inspection of 100-foot contour maps, many of the surface-water samples collected along the Mackenzie River Valley and in northwestern Alberta appear to be located in areas that, theoretically, should be groundwater-discharge areas. Comparison of water qualities from northwestern Alberta and the Mackenzie Valley suggest lower concentrations of dissolved minerals in ponded surface waters along the Mackenzie Valley compared to northwestern Alberta, where, however, the climate is significantly different. This analysis again suggests that the permafrost layer, as suspected, acts as a deterrent to the movement of groundwater.

Preliminary findings by the Alberta Research Council indicate that the concentrations of dissolved minerals occurs in the mineral soil at shallow depths below ground surface whereas surface waters ponded in kettlehole and thermokarst lakes and ponds are relatively low in total dissolved solids (see Fig 23).

A detailed study of the several indicators of groundwater discharge is beyond the scope of this report. It seems certain, however, that groundwater discharge in the form of springs and seepages contributes substantial volumes of water to the Mackenzie River drainage basin. By following the method of J. D. Hem* of plotting stream discharge versus variation in specific conductance, one might obtain a general indication of groundwater flow.

Copies of chemical analyses of water and streamflow data used in this study are included in Appendix 'I'. They were obtained from Dr. L D Delorme in Calgary; from Paul Fee with the Water Quality Division, Inland Waters Branch; and from J N Stein, Pollution Control Section, Resource Development Department of the Environment and the Alberta Research Council.

^{*}USGS Water Supply Paper 1473, "Study and Interpretation of the Chemical Characteristics of Natural Water."

APPENDIX 'B'

EXTRACTS FROM OIL COMPANY SUBSURFACE GEOLOGICAL DATA
FILED WITH THE OIL AND GAS EXPLORATION SECTION OIL AND GAS DIVISION
NORTHERN ECONOMIC DEVELOPMENT BRANCH
DEPARTMENT OF INDIAN AFFAIRS AND NORTHERN DEVELOPMENT, CALGARY

Most oil-company geological reports on deep borehole drilling contain relatively little data that is pertinent to the present study. However, some items of information are worth noting and these have been extracted and listed below. The report number is given along with what is considered to be the more significant subsurface geological information as it relates to regional hydrogeological studies. Descriptions of geographic locations and subsurface geological materials are sometimes vague and difficult to tie down.

- 1 60-4-4 Upper Devonian flat-lying limestone outcrops along the Trout
 River approximately 8 miles above the confluence of the Trout
 and Mackenzie Rivers. Extensive glacial drift covers the
 Upper Devonian strata in this locality.
- 2 508-1-4-8 A testhole drilled at latitude 60°51' and longitude 117°17' is reported to have encountered artesian groundwater.
- 3 508-1-4-8 Structure-test drilling in National Topographic Series mapsheets
 85 D and 95 A encountered between 3 and 144 ft of glacial
 drift overlying Devonian strata.
- 4 509-1-4-1(4) a) The following composite stratigraphic section is given for the region in vicinity of Wrigley:

Depth (ft)	<u>Materials</u>
0 - 100	dark fissile shale
100 - 300	yellow limestone with grey shale interbeds
300 - 800	red shale and massive red limestone
800 - 1300	grey shale and dense grey limestone

b) The following composite stratigraphic section is given for the Great Slave Lake area:

Depth (ft)	Materials
0 - 300	Hay River Formation hard dolomitic
	limestone
300 - 700	Hay River Formation shale with limestone
	and sandstone interbeds
700 - 795	Fort Simpson Formation shale

- 5 352-1-4-17 Soft Upper Devonian shale is said to outcrop along the Mackenzie River banks between latitude $62^{\circ}00$ ' and $63^{\circ}00$ '.
- 6 86-1-4-7 Following data are recorded for the upper Mckenzie River Valley area:
 - a) A borehole at latitude $60^{\circ}52$ ' and longitude $120^{\circ}36$ ' showed 280 ft of glacial drift.
 - b) Boreholes 18 miles east-southeast of Fort Simpson showed between 43 and 500 ft of glacial drift over bedrock.
 - c) The presence of salt water was noted in the Fort Providence area.
 - d) The Martin Hills are reported to be an Upper Cretaceous erosional remnant, which consists of salt-and-pepper sandstone and silty shale at a point 24 miles west of Fort Simpson.
 - e) The immediate Fort Simpson area is underlain by Upper Devonian Fort Simpson Formation shale.
- 7 45-1-5-14(151) Area: National Topographic Series mapsheet 95 N.
 - a) Springs were observed along the North Redstone River at latitude $63^{\circ}32$ ' and longitude $125^{\circ}43$ '. They are said to emanate from a fault zone between Cambrian-Ordovician gypsum beds and the Silurian-Ordovician Mt Kindle Formation.
- 8 96-1-5-1 (218) Lower Root River area: latitude $123^{\circ}15$ ' to $124^{\circ}00$ '; longitude $62^{\circ}20$ ' to $62^{\circ}55$ '.
 - a) In this locality, glacial drift was seen on mountain sides as far up as elevation 3300 ft. Moreover, glacial erratics were found on the tops of all highlands. Alluvial sediments in lowland areas are said to reach 300 ft in thickness.

- b) Upper Devonian strata (shale, limestone, siltstone) are over 10,000 ft thick.
- c) Underlying Middle Devonian limestone strata are said to be 1500 to 2200 ft thick.
- 9 7-11-5-11 (142) Data extracted from several subsurface geological reports is as follows:
 - a) Structurally, Franklin Mountains are an anticlinorium, in which anticlinal axes plunge to the south.
 - b) Near Wrigley, Devonian limestones are seen to outcrop and to dip below the Willowlake River.
 - c) The Franklin Mountains east of the Mackenzie between Ochre River and Blackwater River are composed of heterogeneous limestone strata that form high erosional-remnant ridges and hills.
 - d) Over 150 ft of interbedded shale, limestone, and underlying gypsum beds occur three miles from the Mackenzie River along Saline River. These beds are part of the Saline River Formation. Small creeks in the vicinity are said to be salty and salt encrustations were seen to collect on rocks in creek and river bottoms.
 - e) A Cretaceous sandstone ridge with a gentle regional dip to the west occurs in the Dahadinni River area and is said to be overlain by thick deposits of Quaternary sand and gravel.
 - f) In the Lower Carcajou River area, Sammons Creek is reported to disappear underground of a distance of "several" miles at one point (lat. 65°28'; long. 28°15'), where the strata consist of porous dolomite in the Bear Rock Formation. Anhydrite is interbedded with dolomite and limestone, and the strata are said to be locally cavernous.
 - g) Oscar Creek basin (lat. 65°30'; long. 127°00') near Mount Morrow is said to cover an area of about two square miles that are occupied by small lakes having no outlet. The lakes are believed to discharge into the underlying limestone bedrock. Nearby, deep sinkholes occur in salt and gypsum beds in the lower part of the Bear Rock Formation. Sinkholes occur in evaporites under Bear Rock Formation conglomerate in Mount Richard and Mount Thomas. In the Oscar Creek basin area, the Kee Scarp limestone is reported to be porous and coralline.

- h) Slater River Bogg Creek Halfway Islands area (lat. 65°00'; long. 126°15'). A stratum of 5 ft of silty clay was observed on top of a terrace at the mouth of Slater River.
- i) Shiltee Rock, located seven miles above the confluence of Stony Creek and the Peel River, is a hard Cretaceous sandstone and conglomerate pillar that is 20 feet high.
- j) Discovery Ridge (east of Norman Wells) consists of Devonian and Silurian limestone and dolomite. Norman Wells oilfield is developed in coral-reef limestone.
- k) Alluvial coarse sand and gravel occur along the upper Redstone River (foothills region). Pleistocene and Recent (Holocene) deposits in this area are said to be over 200 ft thick.
- 1) Warm sulphur springs issue from coarse brecciated Bear Rock Formation where the Mountain River cuts the Imperial Range (lat. $65^{\circ}25'$; long. $129^{\circ}10'$).
- m) In vicinity of the headwaters of the East Fork of Little Bear River (across the Mackenzie River from Fort Norman), sediments consist of thick, coarse, massive Tertiary conglomerate and gravel. A borehole on Hoosier Ridge (lat. 65°25'; long. 127°35'; elev: 744) struck salt water at depth of 2817 ft. The water rose to within 100 ft of ground surface. This borehole shows 1600 ft of soft carbonaceous sand, gravel, conglomerate, shale, and lignite.
- n) Two sulphur springs occur on the south bank of the Great Bear River downstream from the lower end of portage road (probably at the rapids section). Exposures along the Great Bear River Valley consist almost entirely of Pleistocene sediments.
- o) In the Beavertail Point region (NTS: 106 H), both Devonian limestone and overlying basal Cretaceous sandstone are reported to be porous and permeable and many sulphur springs occur in the area. The report states that 20 ft of sand (deltaic) over lacustrine silt and clay occur in the lower Donnelly River area.
- p) There is a strong odour of sulphur in waters of the Mackenzie River near Beavertail Point (NTS 106 H).

- q) Depth of glacial drift in the Wrigley area is said to vary from 10 to 1000 ft in thickness.
- r) Two islands in the Mackenzie River opposite Norman Wells -- Goose Island and Bear Island -- are underlain by stratified alluvial silt and sand that is several hundred feet in thickness. Heavy drilling mud is said to be required to drill through glacial drift in the Norman Wells area.
- 10 508-1-46(252). Cameron Hills area in northeastern Alberta and adjoining

Northwest Territories.

- a) Glacial drift in the Cameron River Valley south of Tathlina Lake is reported to be 700 ft thick.
- b) In vicinity of Bistcho Lake in northwestern Alberta, the glacial drift is 865 ft thick, with a gravel stratum from 600 to 865 ft below ground surface.

APPENDIX 'C'

DOCUMENTATION OF PRIVATE COMMUNICATIONS FROM MASCHO, LUND, BRANDON, BREARS, WILDERMAN

- 1. Mr. Paul Mascho, Department of Public Works Yellowknife, Northwest Territories
- a) Fort Norman. The well here is 160 feet deep, and yields approximately 12 Igpm. Chloride content of the water is said to have been high initially and, in addition, has increased with water use.
- b) Fort Providence. Two water wells are in use but the main source of municipal water is the Mackenzie River. The motel is said to have a "good well."
- c) Fort Simpson. Main water supply for Fort Simpson is taken from the Mackenzie River.
- d) Wrigley. The Department of Transport uses groundwater from a well near the Wrigley Airport. Approximately one-quarter of the village water consumption comes from wells.
- e) Fort Good Hope. This community developed a groundwater supply by installing a crib in a spring in an esker. Well depth reported to be 16 to 18 feet and the crib size, 6 feet x 6 feet. The iron content varies from 3 to 4 ppm; otherwise, the water quality is good. However, the spring froze over in 1970, apparently because of traffic along a nearby road. The well has been relocated in order to overcome this problem. It is suspected that the spring may be recharged through shallow sand and gravel from a lake 3 to 4 miles away.
- f) Inuvik. River water is pumped directly from the Mackenzie River into Hidden Lake in order to settle out a silt content of approximately 250 ppm in the summer and a silt content of 20 to 25 ppm in the winter. Inuvik is presently experimenting with settling tanks to remove the river silt.

2.

2. Mr. Sven Lund, water-well drilling contractor at Yellowknife, Northwest Territories

a) Lund owns three drilling rigs, and requently uses a Nodwell-mounted combination of rotary and cable-tool rigs.

- b) Lund has installed water wells at Fort Norman and Wrigley and has test drilled at Norman Wells in connection with groundwater exploration there. At Fort Norman, elevation of the well is approximately 40 to 60 feet above river level. The glacial drift aquifers are 4 to 5 feet thick and wells in the overburden tap several sections of sand. Water quality has deteriorated with usage. At Wrigley, testholes drilled for the Department of Transport encountered cemented gravel below a high terrace. The well at Wrigley is approximately 200 feet deep. Static water level is approximately 100 feet below ground surface. Quantity of water developed is said to be sufficient for local needs.
- c) Lund says that groundwater temperatures range from $38^{\circ}F$ to $40^{\circ}F$ in northern localities where water wells have been installed.
- d) Lund commonly uses 5- or 7-inch well casing, and frequently installs surface casing.
- e) At Norman Wells, the top 100 feet of drift overburden contains zones of frozen sand and gravel that yield no water. Where encountered, shale bedrock below the overburden is hard and contains no significant water-bearing fractures or fissures.
- f) Lund has done most of what little water-well drilling and installation work that has been carried out along the Mackenzie River Valley. Considerable shallow testhole drilling has been done by Big Indian Drilling; and Hall Drilling has done a limited amount of drilling for seismic investigations in vicinity of Fort Simpson.
- g) Lund says that frozen sand and gravel is difficult to drill through owing to caving problems.

- 3. Mr. Leo V. Brandon, Regional Manager
 Department of Indian Affairs and Northern Development
 Whitehorse, Yukon
- a) Probably the best aquifers occur in thick alluvium along the larger rivers, even though some bedrock formations -- such as Middle Devonian Bear Rock Formation limestone, locally -- may yield potable water.
- b) Permafrost is not necessarily a barrier to groundwater development because in the past numerous groundwater supplies have been developed in permafrost regions.
- c) Existing northern communities are not necessarily located in good locations from an engineering, economic, or environmental standpoint. Future northern communities and northern camp-site locations should give more consideration to such factors as water supply, drainage, and, if located on or near a major water course, the velocity of the river water and consequent serious problems of bank erosion and riverbed scour.
- d) Mr. Brandon has observed many locations in the field that would be favorable for the development of groundwater supplies. However, he notes, groundwater development should be done by experienced well-drilling contractors under the supervision of competent groundwater hydrologists.
- e) Rivers tributary to the Mackenzie River from the west carry a much higher silt load than rivers draining into the Mackenzie River from the east.
 - f) Mr. Brandon has observed numerous springs along the Rabbitskin River.
- g) Mr. Brandon believes that the deeper groundwater flow system passes below the Mackenzie River and surfaces along the contact of sedimentary rock strata and the Precambrian Shield. Evidence to support this contention is the apparently more highly mineralized waters in Marian Lake (west of Fort Rae, NWT),

and shown on National Topographic Series mapsheet 85 K) and the lower reaches of Little Buffalo River above Great Slave Lake (shown on National Topographic Series mapsheet 85A).

- h) Available well logs and drilling records, as at 1964, are contained in Mr. Brandon's paper titled "Groundwater Hydrology and Water Supply in the District of Mackenzie, Yukon Territory, and Adjoining Parts of British Columbia," Geological Survey of Canada, Paper 64-39.
- 4. Mr. Lou Brears, water-well driller with M R Hall Drilling, Regina
- a) When drilling for seismic investigations in the area immediately west of Fort Simpson, Mr Brears said he encountered up to 100 feet of unconsolidated stratified (deltaic) sand. The testhole that encountered this thick section of sand is located about 4 miles north of Antoine Lake. This would indicate that the community of Fort Simpson might possibly investigate groundwater supplies in these deltaic sands rather than treat Mackenzie River water. A good location to test for potential groundwater supplies would be in vicinity of nearby Martin River.
- b) Some of the testholes drilled by Mr Brears along the Mackenzie River lowland encountered weakly artesian pressures in the groundwater. Boreholes would flow from 4 to 12 hours that is, until the pressure was sufficiently reduced. The discharging water would then freeze, indicating that permafrost restricts groundwater flow.
- c) Mr Brears encountered loss-of-circulation problems frequently when drilling in permafrost. This situation was most evident, he said, when unfrozen soil zones occurred between frozen soil layers.

- Mr. Giles Wilderman
 Big Indian Drilling Co. Ltd.,
 Calgary
- a) Shallow drilling between Fort McPherson and Fort Simpson was conducted using a rotary-air combination. Compressed air was initially cooled from 150°F to 45° to 50°F, which was a sufficient reduction in temperature if drilling progress was relatively fast. However, it became necessary to drop the air-drilling temperature to 10°F to 15°F if drilling progress was relatively slow. Also where adverse drilling problems were encountered, it became necessary to drop the temperature to 10°F to 15°F to eliminate thawing.
- b) Permafrost-affected soils are best drilled with a combination of rotary-air and cable-tool rig. Refrigeration of compressed air used in drilling is not economical on most small jobs.
- c) Most seismic shotholes along the Mackenzie River Valley are 60 to 100 feet deep. Consequently, they frequently do not pass through the permafrost layer.
- d) Wilderman says that Dr Ralph Isaacs of the Geological Survey of Canada in Ottawa is drilling relatively shallow testholes along the Mackenzie River Valley, and it may be desirable to extend these testholes to depths of several hundred feet (400 to 500 ft), which can be accomplished with the drilling equipment on the job.
- e) Mr Wilderman says that they did not encounter any groundwater artesian conditions (flowing holes) in their shallow (10 to 50 ft) testhole drilling program that extended from north of Fort McPherson and to south of Fort Simpson.

CAMBRIAN

€cs

Saline River Formation evaporites (salt, anhydrite gypsum, and red beds) and underlying Mt Cap Formation green shale and Mt Clark Formation reddish-purple sandstone. Mainly ground-water recharge areas at higher elevations in the Franklin Mountains and ground-water discharge areas at lower elevations near the Mackenzie River. Expect large quantities of poor quality sulphate and chloride waters in the Saline River Formation.

PROTEROZOIC

Precambrian argillite, quartzite and dolomite. Only one small area is shown.

(Geology is modified after GSC Map 30-1963; GSC Memoir 273; GSC Papers 60-19, 61-13, 68-25, 71-11, with accompanying maps and figures; The Development of Sedimentary Basins in Western and Arctic Canada, by P.A. Ziegler (1969), Alberta Society of Petroleum Geology; J. Law in Bull. Can. Pet. Geol. Vol. 19, No. 2, 1971; and J.P.A. Noble and R.D. Ferguson in Bull. Can. Pet. Geol. Vol. 19, No. 3, 1971.)

APPENDIX 'G'

LEGEND OF RECONNAISSANCE BEDROCK HYDROGEOLOGY MAP

(Note: The entire study-area is underlain by widespread permafrost in the discontinuous permafrost zone; also estimates of yields refer to probable, not absolute, maximum figures)

Symbol Symbol	<u>Explanation</u>
Т	Tertiary non-marine sand, gravel, conglomerate, shale, sandstone, coal. Expect maximum yields of 50 Igpm of fair to good quality waters
Ku	Upper Cretaceous mainly non-marine sandstone and shale. Expect maximum yields of 25 Igpm of poor to locally fair quality waters
K1	Lower Cretaceous mainly marine shale and sandstone. Expect maximum yields of 1 Igpm of poor quality sulphate waters
K1f	Upper Cretaceous Fort St. John Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
K	Upper and Lower Cretaceous unnamed and undivided mainly marine shale and sandstone. Expect maximum yield of 5 Igpm of generally poor quality waters
CPa	Carboniferous (Pennsylvanian) and Permian sandstone and conglomerate. Expect maximum yields of 25 Igpm of poor to locally fair quality waters
Dur	Upper Devonian Redknife Formation mainly marine shale and sandstone. Expect maimum yields of 1 Igpm of generally poor quality waters
Duu	Upper Devonian unnamed mainly non-marine shale, siltstone, limestone, and sandstone. Expect maximum yields of 5 Igpm of poor to fair quality waters
Dui	Upper Devonian Imperial Formation mainly non-marine shale and sand- stone. Expect maximum yields of 5 Igpm of generally poor to local- ly fair quality waters
Duk	Upper Devonian Kakisa Formation limestone. Expect maximum yields of 5 Igpm of poor to fair quality bicarbonate waters
Dutt	Upper Devonian Trout River and Tetcho Formations consisting mainly of limestone with some shale and sandstone. Expect maximum yields of 5 Igpm of poor to locally fair quality generally bicarbonate waters
Dus	Upper Devonian Fort Simpson Formation marine shale and siltstone. Expect maximum yields of less than 1 Igpm of generally poor quality sulphate waters
Dm	Middle Devonian mainly carbonate strata with minor shale and anhydrite. Expect maximum yields of 25 Igpm of variable quality waters

Symb	<u>Explanation</u>
Dmk	Middle Devonian Kee Scarp Formation reefal limestone and other limestones. Expect maximum yields of 100 Igpm of poor to locally fair quality generally bicarbonate waters
Dmki	Middle Devonian Kee Scarp Formation limestone and Hare Indian calcareous shale. Expect maximum yields of 25 Igpm of variable quality generally bicarbonate waters
Dmh	Middle Devonian Hume Formation limestone. Expect maximum yields of 10 Igpm of variable quality generally bicarbonate waters
Dmc	Middle Devonian Canol Formation shale. Expect maximum yield of 1 Igpm of poor quality sulphate waters
Dmc	Middle Devonian Canol and Hare Indian Formations consisting mainly of shale. Expect maximum yields of 1 Igpm of poor quality bicarbonate-sulphate waters
Dmb 1	Middle Devonian Bear Rock Formation dolomite, limestone, and anhydrite. Expect maximum yields of 250 Igpm of very poor quality generally bicarbonate-sulphate waters
Dmh	Middle Devonian Hare Indian Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
OS	Undivided and unnamed Ordovician and Silurian dolomite and limest- one. Expect maximum yields of 10 Igpm of highly variable quality generally biacrbonate-sulphate waters
OSk	Ordovician and Silurian Mt. Kindle Formation dolomite and anhydrite, Franklin Mtn. Formation dolomite and shale. Expect maximum yields of 100 Igpm of poor to fair quality generally bicarbonatesulphate waters
€cs	Cambrian Saline River Formation anhydrite gypsum and salt, Cap Mt. Formation shale and Mt. Clark Formation sandstone. Expect maximum yields of 100 Igpm of poor quality generally sulphate-chloride waters from the Saline River salt and anhydrite, 1 Igpm of poor quality waters from the Cap Mt. Formation shale, and 10 Igpm of poor to fair quality waters from the Mt. Clark Formation sandstone
P	Precambrian argillite, quartzite, and dolomite. Expect maximum yields of 25 Igpm of fair quality waters

APPENDIX 'H'

SUMMARY OF FINDINGS OF GROUND-WATER AND GEOLOGICAL

INVESTIGATIONS IN PERMAFROST REGIONS AS THEY APPLY TO THE

MACKENZIE VALLEY REGION -- A LITERATURE ABSTRACT

Abu-Lughod, J., W. J. Roberts and J. B. Stall (1957) "Industrial Operations under Extremes of Weather," <u>Part 5, Problems of Industrial Water in Areas of Extreme Weather Conditions</u>, Meteorol. Mon., Vol. 2, No. 9, pp. 66-86

Abstract

Large yields of potable water are found in aquifers beneath permafrost, particularly in river valleys. Temperature of the ground water is commonly high enough to prevent freezing of the distribution system. Ground water occurs in bedrock fissures, at contacts, and in structural depressions beneath permafrost.

Alaska's Health (1951) "Safe Wells Need Careful Plans," Alaska's Health, Vol. 9, p. 7

Abstract

Suggestions for the proper location of wells with respect to sewage disposal facilities and a detailed plan for a safe well suitable for Arctic conditions are given.

Alter, A. J. (1949) "Water Supply Problems of the Arctic," Alaska's Health, Vol. 7, No. 3, pp. 1-3

Abstract

Brief discussion of water supply in permafrost regions, including the utilization of ground water.

Alter, A. J. (1950a) "Arctic Sanitary Engineering," Washington Federal Housing Administration, p. 106

Abstract

Shallow suprapermafrost water provides a seasonal supply that is easily contaminated. Rarely, water is entrapped with the permafrost in the southern part of the permafrost zone; but the yield is variable. Subpermafrost water supplies are difficult to locate, costly to develop, and commonly highly mineralized. In the Arctic, where permafrost extends into bedrock, circulation of ground water beneath permafrost is hindered by impermeable bedrock formations, and recharge through the permafrost is impossible. At Fairbanks, several wells tap subpermafrost water; the warmest water is available at some distance below the base of permafrost.

Barnes, D. F., and G. R. MacCarthy (1956) "Tests of Geophysical Prospecting Techniques in areas of Sporadic Permafrost in Interior Alaska,"

Geological Society of America Bulletin, Vol. 67, No. 12, Part 2, p. 1805

Abstract

Tests were made of resistivity and seismic refraction techniques in prospecting for ground water near Fairbanks, Big Delta, and Tok. The seismic refraction method proved excellent for detecting permafrost and mapping its upper surface, but was not successful in mapping the lower boundary of permafrost or the upper surface of bedrock. Resistivity techniques were fairly reliable in indicating the presence of permafrost and estimating its thickness; lack of adequate interpretation curves and the effects of severe lateral variations in surface resistivity limited the accuracy of depth measurements.

Bateman, J. D. (1949) "Permafrost at Giant Yellowknife," Royal Soc. Canada Trans., Vol. 43, Ser. 3, Sec. 4, pp. 7-11

Abstract

Permafrost, which is not present in outcrops, extends to a depth of 280 feet where the thickness of the overlying lacustrine clay approaches 60 feet. The clay overburden is regarded as an insulating blanket that has preserved ancient permafrost, and was deposited during a late glacial or Recent high level of Great Slave Lake. The age of the permafrost, therefore, is greater than that of the overburden, and is late glacial or interglacial.

Benninghoff, W. S. (1952) "Interaction of Vegetation and Soil Frost Phenomena," Arctic, Vol. 5, No. 1, pp. 34-44

Abstract

Distribution of permafrost beneath a river flood plain is sketched. Spruce-covered cut banks are underlain by permafrost at shallow depth, but river channels and bars are lacking in permafrost or have a deep permafrost table. Ground which permits the greatest degree of water penetration usually thaws to the greatest depth each summer, but root systems tend to restrict the downward penetration of water.

Billings, C. H. (1953) "Protecting Underground Utilities Located in Arctic Regions," Water and Sewerage Works, Vol. 100, No. 11, pp. 441-447

Abstract

Ground water occurs above, within, or beneath permafrost; the water below permafrost is like that in other climatic regions and is the most dependable source of supply. The water within permafrost is in passages like those in limestone and is generally under pressure, because the free level of its source is likely to be that of a lake or stream above ground. The water above permafrost in summer moves by

gravity, percolating down the slope of the frost table; in winter, when the water begins to freeze, it becomes confined and moves under pressure. If under sufficient hydrostatic head, the water may burst through the top of the ground to form icings.

Black, R. F. (1950) "Permafrost, in Trask, P.D.," Applied Sedimentation, John Wiley and Sons, New York, pp. 247-275

Abstract

Definitions, summaries of terminology, distribution, character, temperature, relation to terrain features, origin, and geologic, engineering, and biologic significance of permafrost are given.

Large year-round supplies of water in the continuous-permafrost zone are found only in deep lakes or large rivers which do not freeze to the bottom in winter. In the U.S.S.R. artesian water has been found beneath 700 to 1,500 ft of permafrost. In the discontinuous-permafrost zone large supplies of ground water are found perched on top of permafrost or in unfrozen zones within or beneath the permafrost. Water-supply problems in the sporadic permafrost zone are comparable to those of the temperate regions. Quality of water is generally inferior to that of temperate regions.

Black, R. F. (1957) "Some Problems in Engineering Geology Caused by Permafrost in the Arctic Coastal Plain, Northern Alaska," Arctic, Vol. 10, No. 7, pp. 230-240

Abstract

Potable ground water is absent except in the beds of larger rivers and lakes. Shallow wells have encountered only saline water within and below permafrost. Potable water is trapped on permafrost in many lakes of the coastal plain. Lakes deeper than 6 ft do not freeze to the bottom and may provide a limited supply of water throughout the year. Very limited quantities of water may be obtained in summer from the active layer and from some of the offshore bars, but the water contains organic material and dissolved salts.

Black, R. F. (1958) "Permafrost, Water-Supply, and Engineering Geology of Point Spencer Spit, Seward Peninsula, Alaska," Arctic, Vol. 11, No. 2, pp. 102-116

Abstract

Point Spencer is the northern tip of a spit that separates Port Clarence from the Bering Sea and is located 69 miles northwest of Nome. Gravel and sand that compose the spit deposits are perennially frozen and cemented with ice; frozen ground underlies most of the area and extends several feet beyond the shore. In many places there is more ice than normal pore space in the sediments. The top of permafrost

generally parallels topographic form. The base of permafrost determined in two wells was 12.5 and 17 ft below the surface, or 7.5 and 8 ft below sea level; the base of permafrost probably conforms roughly to topography. An icing mound 30 ft in diameter was underlain by a lens of ice 1 ft thick; polygonal patterns on the older part of the spit seem analogous to ice-wedge polygons elsewhere in the Arctic, but they were not investigated.

Fresh water is derived from rain and snow melt and is trapped as perched ground water in irregularities on the top of the permafrost. In winter much of the water is frozen. Water is most abundant in the borrow pits excavated in permafrost between the runway and Port Clarence, and in fresh-water ponds.

Boyd, W. L. and J. W. Boyd (1959) "Water Supply Problems at Point Barrow," American Water Works Association Journal, Vol. 51, No. 7, pp. 890-896

Abstract

Attempts to utilize ground water at Point Barrow, Alaska, have been unsuccessful. Drilling during exploration for oil in the Naval Petroleum Reserve produced subpermafrost water with a salinity of several thousand parts per million. Treatment of lake water, used as a supply, is necessary because the concentration of minerals in unfrozen water increases with increased ice thickness.

Brandon, L. V. (1960) "Northern Settlements," No. 1, Preliminary Notes: Canada Geological Survey Topical Report 28, 29 pp.

Abstract

A study of ground-water conditions at most of the settlements in the District of Mackenzie, Northwest Territories, was made in 1960 as part of a study of the occurrence of ground water in the permafrost regions of Canada. Most of the Paleozoic dolomite and limestone in the western Great Slave Lake region and Mackenzie Valley are aquifers containing water that is high in salt and sulfur. Precambrian rocks are satisfactory aquifers for domestic supplies only where fractured. The best aquifers are sand and gravel of alluvial and glacial deposits. Permafrost, where continuous and deep north of the Arctic Circle makes utilization of wells difficult. In relatively thin permafrost little heat is required from the water in the aquifer, or from a built-in heating unit, to keep the well open. Wells offer a potential means of supplying water where surface water has high turbidity, or required expensive intakes, filtration, plants, or pipelines.

Brandon, L. V. (1963) "Evidences of Ground Water Flow in Permafrost Regions,"

Proceedings: Permafrost International Conference, National Academy of
Sciences - National Research Council, Publication 1287, pp. 176-177

Abstract

Springs and drilled wells provide evidence for ground water flow. Three other forms of evidence are apparent in ground-water discharge areas. These are base flow of rivers, variations in the chemical composition of river waters, and vegetation peculiar to an area as a consequence of ground water discharge. Resources do provide evidence of winter flow which can, in part, be attributed to ground water discharge.

Brandon, L. V. (1965) "Groundwater Hydrology and Water Supply in the District of Mackenzie, Yukon Territory, and Adjoining Parts of British Columbia," Geological Survey of Canada Paper 64-39, 102 pp.

Abstract

This report is based on a reconnaissance study of the ground-water hydrology of the District of Mackenzie (527,490 square miles), Yukon Territory (207,076 square miles), and a small adjacent part of British Columbia.

Field work was carried out during the summers of 1960 and 1961, when the writer travelled by aeroplane, canoe, and car over part of the area and visited settlements, type locations, and places where springs are known to occur.

The report is in three parts. The first part outlines the ground-water hydrology of the area and indicates the effect of physiography and geology on streamflow. The second part describes a number of thermal springs in the area. The third part describes the availability of groundwater in many towns and settlements.

Brewer, M. C. (1955) "Geothermal Investigations of Permafrost in Northern Alaska," American Geophysical Union Transactions, Vol. 36, No. 3, p. 503

Abstract

Maximum depth of permafrost is 1,330 ft, and the minimum temperature is -10.6°C, recorded below the depth of seasonal temperature fluctuation (70-100 ft). Lakes deeper than 7 ft do not freeze to the bottom in winter and may have an unfrozen zone approaching several hundred feet in depth beneath them. Frozen ground within the upper 100 ft of depth probably does not extend outward more than a few tens of feet from the shore of Arctic Ocean, although frozen ground may be present at greater depths.

Brewer, M. C. (1958a) "The Thermal Regime of an Arctic Lake," American Geophysical Union Transactions, Vol. 39, No. 2, pp. 278-284

Abstract

Permafrost underlies the shallow lakes, but an unfrozen basin several hundred feet deep may extend beneath the deep lakes.

Brewer, M. C. (1958b) "Some Results of Geothermal Investigations of Permafrost in Northern Alaska," <u>American Geophysical Union Transactions</u>, Vol. 39, No. 1, pp. 19-26

Abstract

Depth of permafrost varies with latitude, length of seasons, surface cover, proximity to the ocean, and distribution of rivers and large lakes that do not freeze to the bottom. Depth of permafrost decreases from 1,330 ft 8 miles from the ocean to indicated depths of 1,045 ft at a point 1,200 ft from the sea, and 670 ft at a point 400 ft from the ocean; the latter depths are slightly modified by nearby lakes. Permafrost temperature increases rapidly toward the ocean. At a point 390 ft from land, data suggest that permafrost is present to more than 400 ft below the sea bottom. Ocean bottom temperatures are below 0°C until ocean depths at 500-1,000 ft are reached, and therefore permafrost must extend seaward to ocean depths of 500-1,000 ft. The driller's log of the hole drilled in the ocean floor indicated no frozen material to 100 ft and the possibility of frozen ground from 100 to 205 ft and the unfrozen layers from 205 to 326 ft below the ocean floor. However, all the formations but the upper few feet have temperatures below 0°C, and are by definition perennially frozen.

Lakes are divided into two groups: (1) those that are 2-3 ft deep and freeze to the bottom in winter, and thaw to a few feet beneath their beds each summer, and (2) those that are 6-9 ft deep, do not freeze to the bottom each winter, and have much deeper thawed zones beneath their beds. Lakes having a diameter of half a mile and a depth of at least 7 ft may have thawed basins beneath them to a depth of 200 ft or more. If the lakes are underlain by sand or gravel of favorable waterbearing characteristics, they could provide a small year-round supply of fresh water. Within 5 miles of the coast, the sediments beneath such lakes may contain saline water.

Permafrost temperatures beneath small rivers that freeze to the bottom each winter are modified by the warming action of river water. Drilling on a bar along the Shaviovik River and at sites one-quarter mile on either side of the river show that the river produced a 3°C warming of permafrost temperature to a depth of 135 ft. Temperatures of these holes are expected to converge with the normal permafrost temperature gradient at greater depth.

The best year-round water source in the Arctic is an uncontaminated lake or stream, having a minimum water depth of at least 7 or 8 ft.

Broadwell, J. A. (1945) "How CAA Engineers Meet Construction Problems North of the Arctic Circle," <u>Pacific Builder and Engineer</u>, Vol. 51, No. 4, pp. 55-56

Abstract

The Civil Aeronautics Administration airstrip at Kotzebue, Alaska, is on a sandy beach ridge about 50 ft from Kotzebue Sound. Fresh water

was obtained by digging a shallow well only 100 ft from the sound. Water level in the well was 5 or 6 ft below sea level. Permafrost between the site of the well and the sound formed a barrier to encroachment of salt water. Softening and chlorination of the well water was necessary. At Shungnak, Alaska, a well was dug less than 100 ft from the riverbank of the Kobuk River. The well passed from sandy soil into gravel, but it was entirely in frozen ground. No water was found at least 15 ft below the level of the river. The hole was filled with gravel and converted into a cistern into which river water was pumped.

Brooks, A. H. (1907) "The Circle Precinct (Alaska)," <u>U.S. Geological Survey</u> Bulletin 314-K, pp. 187-204

Abstract

On Harrison Creek the gravel deposits are not frozen, and water circulates freely throughout the year. Creek-valley alluvium along Eagle Creek is 8-20 ft thick, of which 5-15 ft is muck; the gravel is not frozen and contains freely circulating water all winter. Similar water-bearing unfrozen zones occur in the alluvial deposits on Deadwood Creek.

Brown, I. C. (1958) "Geological Map of the District of Mackenzie, Northwest Territories," Map 1055A, Geological Survey of Canada

Abstract

 $\mbox{{\sc Map}}$ relevant to the geology of the Mackenzie River Valley Region, N.W.T.

Brown, R. J. E. (1967) "Permafrost in Canada," <u>Map 1246A, Publication No. NRC 9769</u>, A Joint Publication of The Geological Survey of Canada and The Division of Building Research

Abstract

This map shows the areal distribution of continuous and discontinuous permafrost in Canada.

Brown, R. J. E. (1969) "Factors Influencing Discontinuous Permafrost in Canada," <u>The Periglacial Environment</u>, Edited by Troy L. Pewe, McGill-Queens University Press, Montreal, pp. 11-55

Abstract

Discontinuous permafrost forms a broad transition between areas with no permafrost and the continuous zone. From a study of available literature and field observations over the past decade, the approximate distribution and nature of the discontinuous zone in Canada has been established. East of Hudson Bay, discontinuous permafrost extends from the Laurentide Scarp, north to about 58° north. Between Hudson Bay and the Cordillera it extends northwesterly in a broad band several hundred

miles wide to include the northern portions of the provinces and the southern portions of the territories. In the Cordillera, permafrost occurs at high elevations south to the 49th parallel and farther. Climatic control of the broad pattern of permafrost distribution is borne out by its relation to mean annual air temperature. Between the 30°F and 25°F mean annual air isotherms permafrost islands vary from a few feet to several acres in extent, to a maximum of about 50 feet in thickness, having temperatures between 30°F and 32°F. Between the 25°F and 20°F mean annual air isotherms, permafrost is widespread, 50 to 200 feet thick having temperatures down to approximately 23°F. Permafrost is virtually continuous north of the 20°F mean annual air isotherm. Climate is responsible generally for the existence of permafrost but the distribution of individual islands is conditioned by variations in microclimate and terrain features such as relief, drainage, vegetation, and snow cover. The extent of permafrost fluctuates in response to changes in climatic and terrain features with time. permafrost in Canada's discontinuous zone probably formed after the final retreat of Pleistocene ice sheets or post-glacial inundations, except in the unglaciated portion of the Yukon Territory where its formation was periglacial.

Cederstrom, D. J. (1951) "Ground Water in Palmer, Anchorage, and Fairbanks Areas, Alaska," U.S. Geological Survey Open-File Report, 6 p.

Abstract

The Fairbanks area consists of a low plain underlain by silt, sand, and gravel, which is perennially frozen in form of wedges ranging in thickness from 0 to 250 ft, and silt-mantled bedrock hills. In the plain at Fairbanks small-diameter wells, 15 to 250 ft deep, obtain water from above or below permafrost. The wells are constructed by the jet-drive method, and no real difficulty is experienced in keeping them in operation. Two-inch diameter wells produce as much as 40 gpm, and the large-diameter wells yield more than 800 gpm. Water quality is poor, largely because of a high-iron content.

Cederstrom, D. J. (1952) "Summary of Ground-Water Development in Alaska, 1950," U.S. Geological Survey Circular 169, 37 p.

Abstract

This report discusses present and possible future ground-water development in a number of localities through Alaska. Substantial development of ground-water supplies is found only in Anchorage, Palmer, and Fairbanks. Elsewhere, few wells are present and possibilities of ground-water development have been almost entirely unexplored. Large quantities of ground water of good to poor quality are available in extensive areas of intermontane sandy fill and sandy glacial deposits. Nothing specific is known of possible yields in hardrock areas, or in rocks of any kind in southeastern Alaska. Much remains to be learned

about ground-water occurrence, particularly with reference to the needs of growing communities, military establishments, and some areas of potential industrial activity.

Permafrost is a factor to be dealt with in development of water supplies in many northerly localities. In the north, permafrost is thick; but it thins southward and becomes more and more discontinuous until it is entirely absent. Except where thick and continuously distributed, permafrost does not preclude ground-water development, for it occurs in many places beneath permafrost or in thawed zones between permafrost. Permafrost is a serious problem north and west of the Alaska Range. Near Fairbanks permafrost is as much as 200 ft thick in the valley flat, but is discontinuous. In the vicinity of major streams and rivers permafrost is ordinarily absent, particularly on the "slip-off" side of the meander, but it is present in the steep face of cut banks on the opposite shore. Even near the cut bank, permafrost may be thin, and it is commonly absent beneath abandoned channels a half mile or more from the river. North of the Brooks Range permafrost many hundreds of feet thick makes ground-water development impracticable, except possibly along the Colville River.

Cable-tool drilling offers no special problems; frozen materials generally stand well in the hole, but casing is required to shut off thawed running sand or silt and to prevent caving due to thawing as the hole warms during the drilling. Casing will freeze to the walls of holes only where permafrost is several degrees below freezing or during periods of idleness. A productive well will not freeze if pumped regularly, and the plug of ice that sometimes forms inside the casing during idle periods can be thawed by hot water, steam, or salt.

Thicknesses of permafrost greater than 150 ft have been penetrated by 2-in. driven wells using cone-shaped drive head, above which are 1/4-in. perforations and through which a 1/2-in. thaw line projects as much as 18 in. The thaw line delivers water at 33° to 40°F which melts sufficient permafrost to permit driving the pipe. At shallow depths skilled drillers can make 30-40 ft per day, but progress below 80-100 ft may be as little as 1 or 2 ft a day.

Shallow wells dug in materials above permafrost supply a small amount of poor-tasting water, but the wells decrease in yield or freeze completely in winter. Supplies are obtained in some places where a depression in the permafrost formed beneath stripped ground or heated buildings.

Cederstrom, D. J., P. M. Johnston and Seymour Subitzky (1953) "Occurrence and Development of Ground Water in Permafrost Regions," <u>U.S. Geological Survey Circular 275</u>, 30 pp.

Abstract

Ground water in permafrost regions occurs mainly in unfrozen ground which is (a) under and adjacent to large rivers; (b) in or near the smaller streams; (c) in or near standing bodies of water, such as lakes occupying abandoned channels or muskeg lakes; (d) in newly deposited alluvium formed

on the concave side of present river meanders but not necessarily adjacent to the river; (3) in dry abandoned channel scars or lakebeds; (f) in places where insulating vegetation mat has been stripped, allowing deep thaw; and (g) on south-facing hillsides. The procedure for surveying ground-water resources follows that of Muller (1945). Description of ground-water recovery includes discussion of drilling methods, drilling fluids, and winterization of drill rigs employed by Government agencies, petroleum and mining companies, and water-well drillers in Alaska and northern Canada.

Water distribution systems and water sources are described for Fairbanks, Nome, Dawson, Yellowknife, Donjek River, Kluane Lake, and Fort Chemo.

Further studies of the occurrence of ground water in permafrost regions should be undertaken along the following lines: (a) Continuation of literature search; (b) establishment of a research investigation, including drilling in some area north of the Arctic Circle in Alaska to obtain data on occurrence within the continuous-permafrost zone; and (c) development of geophysical methods and use of them in alluvial valleys where geologic information and drilling information make checking of the results possible.

Cederstrom, D. J., Clyde Wahrhaftig and F. F. Barnes (1959) "Ground Water Hydrology in Alaska," <u>First International Symposium on Arctic Geology</u>, Calgary, Canada, Vol. 12, No. 12

Abstract

Ground-water studies, begun in 1947, have been made at Fairbanks, Anchorage, Matanuska Valley, Kotzebue, Pribilof Islands, and Bethel. The Tanana Valley, in which Fairbanks is located, with its gravelly fill was found to be one of the most prolific sources of ground water in the world. In this area, permafrost is a minor problem in developing ground water, as is high iron content in the water. Central Alaska may be characterized as an area where large alluvial valley fills contain much ground water. Northward, however, permafrost becomes more and more of a problem.

Chernyshev, M. IA (1935) "Search for Underground Water in Perpetually Frozen Areas," American Water Works Association Journal, Vol. 27, pp. 581-593

Abstract

Finding water in perpetually frozen ground offers difficulties, and the methods used to find it are different from those ordinarily used. They are closely associated with common geologic practice and with the climate in a given region and are difficult to use in other regions. Three types of water occurrence are considered.

1. Subsoil water found in thick alluvium above perpetually frozen ground is the result of infiltration of precipitation and condensation of moisture during the frost-free season. Because of underlying permafrost

the subsoil water is not a source of large supplies, and tends to be erratic in quantity and to dry up toward the end of winter. In winter, when the water-bearing layer is compressed between the downward penetration of winter freezing and permafrost, the water under hydrostatic pressure breaks through to the surface at the weakest point in the seasonally frozen layer. The water forms an icefield; under heated buildings the water can emerge with less difficulty and may inundate the building, freezing and filling the structure with ice. Subsoil water trapped between the seasonal frost and the permafrost is not an abundant and dependable supply of water, and the springs formed are not dependable. It is best developed by erection of shallow wells with timbered frames or underground drain galleries; however, withdrawal of water may exhaust the water-bearing layer and permit freezing of the galleries; so the wells and galleries should be protected from freezing air temperatures, possibly by an earth embankment around well or gallery. The water in regions of perpetually frozen ground is characteristically soft, and sometimes contains high amounts of iron.

2. Springs are a more constant and abundant supply of water, which rises from very deep strata through the permafrost. They occur in the cracks of the scarps and are common in areas underlain by granite and crystalline schists. Springs are of either fresh or mineral water; some hot and warm waters are of the nitrous—acid type, most cold waters are of the carbonic—acid type. Springs are common on sunny slopes and even on mountaintops; their waters saturate the soil downslope, providing sufficient moisture for growth of thickets of trees (some tilted) on ice hillocks. Some springs, when localized, form "ice—volcanoes" at the surface; others, composed of warm water, form open—water channels that pass downslope into icefields. The best time to search for springs is February or March, when they can be recognized by icefields, or "heaps," and because at this time of year a flow probably indicates a spring origin, not an origin in subsoil water.

Reconnaissance investigation of a spring should be made in March to fix its limits, with detailed exploitation of the water source in the summer. During reconnaissance, a topographic survey of the outlet should be made, and the icefield sketched. Velocity of the running water is measured. Where the outlet is under water, the highest temperature measurement will be closest to the spring outlet, and measurement of the direction of currents in an icefield may enable location of the outlet. Shallow borings and excavations to locate the deepest thawed ground and rise of ground temperatures toward the source of water also show the position of the spring outlet. Heads of springs commonly form ice cones in late winter. Definition of the limits of the funnel within which the spring occurs is done during the detailed investigation by a system of "chessboard" borings and pits made near the outlet. From these excavations and borings, geologic maps with notations of permafrost and ground-water level can be made. In the center of the funnel in permafrost, an excavation is made suitable for pumping water. Where the spring outlet is discovered, the whole thawed layer and outlet may be intersected at several points by a collection gallery. Where there are several outlets separated by permafrost, each outlet is blocked and its water diverted to the lowest. Pumping tests and water-level observations should be made, and the waste water led away by way of gutters downslope; at the beginning of pumping the water yield is always more than that established later.

3. Artesian water from beneath the permafrost comes generally from horizons in alluvium in which impermeable confining layers are above and below the water-bearing layer and cause hydrostatic pressure (head). Artesian water occurs, in some places, in perpetually frozen ground, and may also consist of juvenile water; artesian water is found only in comparatively young sedimentary and volcanic formations (Jurassic and Tertiary) and in volcanic formations of Jurassic, Cretaceous, and Tertiary age.

Investigation of artesian water requires detailed geologic examination and deep boring. Temperatures of perpetually frozen ground and of the water are measured to insure that the water passing through the borehole in permafrost will not freeze. Water should be kept flowing through the borehole rapidly to enable the water to warm the pipes and thaw sufficient frozen ground around the pipes. It is also advisable to heat the hole, at the beginning of work, by steam through pipes from the boiler. Further special heating measures are generally not required.

Clark, L. K. and A. J. Alter (1956) "Water Supply in Arctic Areas; Design Features," <u>Journal of Sanitary Engineering Division</u>, Vol. 82, No. SA-2, Paper 931, pp. 931-1-931-11

Abstract

Ground water obtained from wells through permafrost is subject to freezing in the withdrawal pipe from underpumping and to freezing in the aquifer from overpumping. Well and pump installations are subject to damage by frost heaving. Ground water is warmer than surface water in winter and requires less heating before distribution. Water levels fluctuate, reaching the lowest level in late winter and early spring; in some places, well supplies have been entirely depleted at this time of year. Test pumping during the spring low water period will aid in determining reliability of yield.

Craig, B. G. (1957) "Glacial Lake McConnell, and the Surficial Geology of Parts of Slave River and Redstone River Map-areas, District of Mackenzie," Geological Survey of Canada Bulletin 122, p. 33

Abstract

The area was completely glaciated by the Wisconsin Laurentide icesheet, which extended westward into Mackenzie Mountains. There is no evidence that Cordilleran ice entered the area from the west.

A vast glacial lake, Glacial Lake McConnell, which extended from Great Bear Lake through Great Slave Lake to Lake Athabasca, was formed during deglaciation as a result of differential isostatic depression toward the east. This lake originated as three separate lakes in the three basins but became one vast lake as the topographic low between Great Bear Lake and the northwest arm of Great Slave Lake, and the Slave River Lowland became ice-free. Elevations of lacustrine features that formed during the maximum stand of the lake are about 925 feet above sea-level along its eastern boundary and decrease westward. Subsequent isostatic readjustment lowered water levels until the large glacial lake

separated into smaller lakes, one of which was ancestral to Great Slave Lake. The minimum amount of readjustment indicated in this basin is slightly over 2 feet per mile.

During the earliest phases of ice-retreat, flow was diverted to the north and south by the mountain barrier along Mackenzie and Liard Rivers. Subsequent marginal thinning and eastward retreat produced a radial pattern of flow features in the western part of the area. Stagnation on Horn Plateau while ice was flowing actively on either side of it formed two lobes in the east-central part of the map-area. During the last phases of deglaciation flow was to the southwest and the ice-margin was almost parallel with the edge of the Precambrian Shield.

Cronkwright, A. E. (1947) "Water Supply Problems of the Arctic," <u>Public Works</u>, Vol. 78, No. 8, pp. 18-20

Abstract

In Arctic and subarctic regions abundant surface water of good quality can be obtained from rivers and lakes in summer; but in winter surface water is scarce, for rivers freeze nearly to the bottom and have restricted flow, and only the deeper lakes have water beneath the ice cover. At an unspecified Army post on Baffin Island plans were made for obtaining winter water supply from a river that in summer was one-quarter mile wide and 10 to 20 ft deep. Restricted streamflow, thick ice, and drifting snow on the access road rendered these plans impracticable, and water that was mineralized and of high color was obtained from a lake. Permafrost extends into bedrock at least 100 ft below the ground surface at this base and is hard to drill. The possibility of using high-speed rock drills in frozen rock should be investigated. At a large subarctic base, water was distributed by pipelines laid on the surface in insulated boxes. At small bases, a location close to water, such as a deep lake, is required or else snow and ice can be melted for camp use.

Day, J. H. (1968) "Soils of the Upper Mackenzie River Area, Northwest Territories," Research Branch, Canada Department of Agriculture, Ottawa, p. 77

Abstract

The surveyed area consists of approximately 4,787,500 acres in the southwestern part of the Northwest Territories. It includes the lands west of the Hay River in a wide band around the west end of Great Slave Lake and down the Mackenzie River to Green Island. The area is part of the Great Slave Lake Plain. The terrain is mostly level and gently sloping near the lakes and the river, but farther away there are steep slopes. The steepest slopes, which in some places are sheer rock escarpments, mark the highest stand of Glacial Lake McConnell along the south border of the area.

The climate is the continental type. The mean annual temperature is about 25 F; the mean annual precipitation varies from 10 to 14 inches.

The frost-free period (32F) varies from 75 to 106 days, and the growing season (42F) from 130 to 140 days. The Thornthwaite moisture deficiency during the growing season varies from 5.5 to 7.9 inches.

Forest growth covers the area. White spruce and balsam poplar form the main cover types on the river benches. At levels above the river benches, pines, aspen, and in the moist or wet positions, black spruce and tamarack are the tree species.

The most commonly occurring soils are Brown Wooded (30.3%) followed by Organic soils (24.3%), Gleysols (21.5%), Regosols (4.1%), Gray Wooded (2.7%), Podzo Regosols (2.2%), and Humic Gleysols (0.7%). About 1% of the land is moderately and strongly sloping, and about 1.1% is very steeply sloping and hilly. About 40% of the soils are well or imperfectly drained, but 47% are poorly drained. About 27% of the soils have sufficient stones on the surface to hinder cultivation.

About 12% of the soils belong to soil capability class 3 for agriculture, and about 16% belong to capability class 4. The soils in these classes have limitations for agriculture, but are capable of producing cereal and forage crops. About 14% of the soils belong in class 5 and are best suited to the production of forage crops and pasture. About 24% of the soils belong to class 7 and are not capable of use for arable agriculture or permanent pasture.

The soil map, printed on a scale of 1:250,000 (nearly 4 miles-inch), identifies soil areas by colors and symbols. The map also indicates the location of settlements, roads, lakes, and rivers. The report and the map are complementary and both should be studied to obtain information about the soils.

Dickens, H. B. (1959) "Water Supply and Sewage Disposal in Permafrost Areas of Northern Canada," Polar Record, Vol. 9, No. 62, pp. 421-432

Abstract

Permafrost restricts the movement of ground water and limits its use. Supplies obtained from above or within the permafrost are of variable quantity and of doubtful purity. Wells drilled through permafrost are costly and may require controlled pumping or auxiliary heat to prevent freezing of the well. Overpumping may result in freezing of the aquifer.

Dickens, H. B. (1960) "Construction in Permafrost; Obstacles of Soil and Climate," Canadian Consulting Engineer, Vol. 2, No. 1, pp. 33-37

Abstract

The author explains the basic properties of permafrost and discusses the problems of water supply and sewage disposal.

Douglas, R. J. W. and D. K. Norris (1961) "Camsell Bend and Root River Map-Areas, District of Mackenzie, Northwest Territories," Geological Survey of Canada Paper 61-13, p. 36

Abstract

Camsell Bend and Root River map-areas extend from the western Interior Plains on the east to deep within Mackenzie Mountains on the west. The nature and thickness of the stratigraphic succession varies considerably, depending on position relative to the plains or the mountains. In general, about 2,000 to 3,000 feet of strata underlies the plains east of the map-areas. Along the mountain front in McConnell Range of Franklin Mountains, some 6,000 feet is present between the top of the Middle Devonian and the Proterozoic. In Whittaker and Delorme Ranges of Mackenzie Mountains, however, some 15,000 feet of strata was measured below the top of the Middle Devonian; in spite of this great thickness it is unlikely that the top of the Proterozoic was reached.

The succession in Franklin Mountains in McConnell Range and in the vicinity of Root and North Nahanni Rivers has been known for some time through the work of Williams (1922, 1923) and Hume (1922). Several of their rock units were named, and insofar as possible at this time, they are recognized in this report. The thick succession in Mackenzie Mountains and Liard Plateau has been described in previous reports (Douglas and Norris, 1959, 1960) and additional data is presented here. The succession has been divided into a large number of map-units, some of formational status. Other map-units have been introduced to avoid implying correlation of strata in the different ranges where uncertainties exist, and still others to embrace sequences of rocks that were undivided or indivisible.

In this report, names are proposed for some map-units that are considered to have formational status. These units comprise rocks of Ordovician, Silurian and Devonian age exposed in Mackenzie Mountains. The new formations — the Whittaker, Delorme, Camsell, Sombre, Arnica, Manetoe, Funeral, Landry and Headless — are established primarily on the basis of gross lithology and general mappability in these and adjacent map-areas to the south and north; their designation does not fully take into consideration the results of stratigraphic and palaeontological studies still in progress.

Douglas, R. J. W. and D. K. Norris (1963) "Dahadinni and Wrigley Map-areas, District of Mackenzie, Northwest Territories," Geological Survey of Canada Paper 62-33, p. 34

Abstract

The stratigraphic succession beneath the Plains is probably more like that in Franklin Mountains than that of the more easterly Plains (Douglas and A. W. Norris, 1960). The succession in McConnell Range of Franklin Mountains was established by Williams (1922, 1923) at Cap

Mountain and Mount Kindle within Wrigley map-area and at Mount Clark and Saline River just north of the area. He proposed the following Cambrian to Silurian formations: Mount Clark, Mount Cap, Saline River Franklin Mountain and Mount Kindle. Their use here is as close as possible to their original definition, although it has been found necessary to raise the base of the Mount Clark Formation to correspond with an unconformity and the Mount Kindle Formation is now considered to be late Ordovician and early Silurian in age. Most of the formations of the Mackenzie Mountain sequence as established in adjacent Camsell Bend and Root River map-area (Douglas and D. K. Norris, 1961) extend into Dahadinni River map-area. These are the Whittaker, Delorme, Sombre, Arnica, Funeral, Manetoe, Landry and Headless Formations, of Ordovician to Middle Devonian age.

Ellsworth, C. A. (1910) "Water Supply of the Yukon-Tanana Region (Alaska), 1909," U.S. Geological Survey Bulletin 442-F, pp. 251-283

Abstract

Impermeability of the frozen ground prevents significant underground storage of water and makes uniform distribution of the total runoff impossible. Water derived from thawing of frozen ground during summer is of minor importance.

Fernald, A. T. (1959) "Geomorphology of the Upper Kuskokwim Region, Alaska," U.S. Geological Survey Bulletin 1071-G, pp. 191-279

Abstract

Wells at McGrath on the flood plain of the meandering Kuskokwim River provide subsurface data on frozen ground in the lowland. On the older parts of the meander scrolls 5 wells passed through the bottom of permafrost at depths ranging from 15 to 40 ft, and 6 wells at depths of 40-50 ft. Wells on the newer parts of the meander scrolls, including the 262-ft Federal Aviation Agency well, are free of permafrost. At Farewell Federal Aviation Agency airstrip a 360-ft well passed through a zone of permafrost the bottom of which is reported as both 12 and 125 ft by different sources.

Ferrians, Jr., Oscar J., Reuben Kachodoorian, and Gordon W. Greene (1969)
"Permafrost and Related Engineering Problems in Alaska," <u>U.S. Geological</u>
Survey Professional Paper 678, p. 37

Abstract

Permafrost, or perennially frozen ground, is a widespread natural phenomenon. It underlies approximately 20 percent of the land area of the world. The permafrost region of Alaska, which includes 85 percent of the State, is characterized by a variety of permafrost-related geomorphic features including patterned ground, pingos, thaw lakes, beaded drainage, thaw or thermokarst pits, and muck deposits. Known permafrost thickness ranges from about 1,300 feet near Barrow in northern Alaska to less than a foot at the southern margin of the permafrost region. The distribution of permafrost is controlled by climatic, geologic, hydrologic, topographic, and botanic factors.

The extensive permafrost region of Alaska poses special engineering problems for the design, construction, and maintenance of all types of structures. Lack of knowledge about permafrost has resulted in tremendous maintenance costs and even in relocation or abandonment of highways, railroads, and other structures. Because of the unique geologic-environmental conditions that exist in permafrost areas, special engineering procedures should be used, not only to minimize disruption of the natural environment, but also to provide the most economical and sound methods for developing the natural resources of the permafrost region of Alaska.

Fraser, J. K. (1956) "Physiographic Notes on Features in the Mackenzie Delta Area," Canadian Geographer, No. 8, pp. 18-23

Abstract

Associated with landslide debris on the slopes of low hills bordering the eastern margin of the Richardson Mountains, near Aklavik, Northwest Territories, are three pingolike features. Pingos, according to most workers, are formed by hydrostatic pressure in a subsurface layer of unfrozen soil confined by frozen layers. This pressure forces a mixture of water and fine materials upward through a rupture in the upper permafrost layer; their formation appears to require fine homogeneous material saturated with water, as, for example, occurs in shallow ponds or old lake beds. The pingos on the slopes of Mount Goodenough (Black Mtn.) are (1) a conical hill 60 ft high containing a crater with a pool 25 ft across, (2) a circular pool 40 ft across in which the ice was cracked and arched, with mud showing in the crack, and (3) a circular crater about 85 ft in diameter contained by a low rim about 18 ft high and breached downslope. Two theories of origin are advanced: (1) that they are of thermokarst origin, and (2) that their formation is similar to that of pingos.

Feulner, Alvin J. and John R. Williams (1967) "Development of a Ground-Water Supply at Cape Lisburne, Alaska, by Modification of the Thermal Regime of Permafrost," <u>U.S. Geological Survey Professional Paper 575-B</u>, pp. B199-B202

Abstract

A water supply has been developed in formerly frozen alluvium beneath a small intermittent stream by modification of the thermal regime of permafrost. The modification, largely a byproduct of road and reservoir construction, was effected by: (1) removal of tundra vegetation and the upper few feet of alluvium, which allows warming of gravel and water in the summer; (2) construction of a reservoir upvalley, from which water recharges the alluvium during the summer; and (3) installation of galleries downvalley from the reservoir to collect the water. Similar methods may make it possible to obtain water supplies elsewhere in arctic regions where stream alluvium extends below the depth of winter freezing.

Grainger, J. W. (1958) "Water and Sewer Facilities in Permafrost Regions," Municipal Utilities Magazine, Vol. 96, No. 10, pp. 29, 62-67

Abstract

Water in permafrost regions may be obtained from wells, rivers, lakes, ice, and the ocean. River water can be exploited by standard methods or with portable pumps where permafrost, unstable soil conditions, or the problem of ice erosion of river banks exist. Water can be obtained from lakes by extending intake pipe out into the lake. It can be obtained from just below the ice of the Arctic Ocean near the mouths of rivers because the fresh river water floats on the heavier salt water.

Hitchon, Brian, A. A. Levinson and S. W. Reeder (1969) "Regional Variations of River Water Composition Resulting from Halite Solution, Mackenzie River Drainage Basin, Canada," <u>Water Resources Research Vol. 5, No. 6</u>, pp. 1395-1403

Abstract

The composition of surface waters in the Mackenzie River drainage basins falls into three general groups: (1) rivers entering the Slave-Mackenzie system from the west which have sum-of-constituents 100-200 mg/l and chloride in the range <1 mg/l in their headwaters to 2-5 mg/l at their mouths; (2) surface waters on the Canadian Shield which have lower sum-of-constituents (<100 mg/l) and chloride (<1 mg/l); and (3) the Slave and Mackenzie rivers and the Great Bear and Great Slave Lakes, which have sum-of-constituents 100-200 mg/l and chloride 5-10 mg/l. Hydraulic head cross sections with evidence of solution collapse structures and anomalous depositional thicknesses indicate extensive solution of Middle Devonian halite and movement of the resulting brines to discharge areas at the principal Devonian outcrop near the Slave River. Chemical and isotopic analysis of saline springs in the discharge area confirms an origin by solution of halite (and gypsum) by meteoric water.

Hopkins, David M., Thor N. V. Karlstrom and Others (1955) "Permafrost and Groundwater in Alaska," U.S. Geological Survey Paper 264-F, pp. 113-145

Abstract

The distribution of ground water in Alaska affects and is affected by the distribution of permafrost. Present knowledge of permafrost and groundwater conditions is summarized for the following representative areas of Alaska: The Arctic slope and northern Seward Peninsula in the continuous-permafrost zone; southern Seward Peninsula, the Yukon Flats, the middle Tanana Valley, and the upper Kuskokwim Valley in the discontinuous-permafrost zone; the Britol Bay region in the sporadic-permafrost zone; and the Kenai lowland in the no-permafrost zone. The application and limitations of aerial-photograph interpretation in permafrost studies also are discussed.

Regional climatic differences result in a transition from thick, continuous permafrost in northern Alaska to permafrost-free terrain in southern Alaska. However, local differences in topography, lithology, and drainage result in sharp local differences in the character and distribution of permafrost that tend to obscure the regional zonation. Moreover, frozen ground formed during past cold periods persist to the present time in many areas, so that the distribution pattern is not exclusively the product of present-day climates.

Much of the ancient frozen ground is differentially thawing today. Recently formed frozen ground also thaws locally where natural or artificial alteration of the landscape alters the thermal regimen of the ground. Thus, both recent and ancient permafrost are interrupted horizontally and vertically by thawed zones through which ground water may circulate. Conditions that favor active circulation of water, both at the surface and at depth, promote thawing of permafrost and retard formation of new permafrost. Consequently, potential aquifers are similar in character but more restricted in size and abundance in permafrost areas than in areas of no permafrost.

Aerial photographs are almost indispensable to geomorphic studies in Arctic and subarctic regions. Their use permits recognition of many features and geomorphic relationships difficult to discern on the ground and allows controlled extrapolation of field data into nearby areas.

Hubbs, G. L. (1963) "Water Supply Systems in Permafrost Areas," <u>Proceedings</u>:
Permafrost International Conference, National Academy of Sciences -National Research Council, Publication No. 1287, pp. 426-429

Abstract

Adequate water supply is basic for the continued growth of any community. In permafrost areas the attendant difficulties in providing this supply are numerous and complicated. The main concern here is to find workable solutions for safe and plentiful water supplies that are economically feasible for both large and small communities.

Hughes, O. L., V. N. Rampton and R. J. Fulton (1968, 1969, 1970) "Reconnaissance Maps of Surficial Geology along the Lower Mackenzie Valley and adjoining Coastal Plains," on open file in the Geological Survey of Canada Office in Calgary.

Abstract

These maps comprise a generalized overview of the surficial materials along the lower portion of the Mackenzie River Valley and Arctic lower coastal plain.

Hume, G. S. (1954) "The Lower Mackenzie River Area, Northwest Territories and Yukon," Geological Survey of Canada Memoir 273, p. 118

Abstract

This publication contains three maps on the geology of the Mackenzie River Area.

Hyland, W. L. and M. H. Mellish (1949) "Steam Heated Conduits -- Utilidors -- Protect Pipes from Freezing," Civil Engineer, Vol. 19, No. 1, pp. 27-29

Abstract

Churchill, Manitoba, Canada, obtains its water by way of pipeline from a lake; the subsoil is not suitable for wells. At Fairbanks, Alaska, individual domestic wells are as deep as 200 ft; the sandy and gravelly soil is perennially frozen, but is water-bearing below and between layers of permafrost.

Hyland, W. L. and G. M. Reece, (1951a) "Water Supplies for Army Bases in Alaska," New England Water Works Association Journal, Vol. 65, No. 1, pp. 1-16

Abstract

Near Fairbanks, shallow lakes and streams, deep freezing in winter, flat terrain, and high suspended load of some streams make development of surface-water supplies impracticable. Adequate supplies of ground water are found below permafrost at depths of 60-180 ft. The water is about 35°F and does not meet the U.S. Public Health Service standards for iron and manganese content. The high iron and manganese content seems characteristic of permafrost regions. Because of the high cost of shipment of dry chemicals, and because base regulations required 0.4 ppm chlorine in the treated water, the chlorine method was found most practicable for removing the iron and manganese and at the same time adding chlorine to the water. Chlorine is applied to the water and is followed by settling and sand filtration.

Janson, Lars-Eric (1963) "Water Supply Systems in Frozen Ground," <u>Proceedings</u>:

<u>Permafrost International Conference</u>, National Academy of Sciences -
National Research Council Publication No. 1287, pp. 430-433

Abstract

Consideration must be given to several factors when determining an underground layout depth for water pipelines and sewers. In northern Sweden, the zero-isotherm or frost-free depth, is in most cases the only determining factor.

In these areas, the frost depth is very uncertain and, to a large extent, extremely sensitive to variations in the mean annual temperature, especially in snow-cleared ground. As stated in an earlier publication, a succession of years with cold winters along with cool summers and autumns or little precipitation may result in lowering of the mean annual temperature of the ground to 0° or below. This implies that the frost depth may, at a certain critical mean annual temperature in the ground, suddenly go much deeper than normal.

Mean temperature variations in these areas make it difficult to establish a frost depth which will be decisive in choosing a laying depth for water pipelines. A 2.4 to 2.6 m laying depth has been adopted for the present; it corresponds to the frost depth of most cold winters. Because frost depth may be considerably greater, freezing in pipelines will be fairly frequent. This is confirmed by the fact that every year large sums are spent on repair and thawing of frozen water pipelines and sewers.

Jenness, J. L. (1949) "Permafrost in Canada," Arctic, Vol. 2, No. 1, pp. 13-27

Abstract

The bed of the Mackenzie River near Norman Wells is unfrozen. Wells 100 ft, 200 ft, and 350 ft from the water encountered permafrost thicknesses of 60 ft, 135 ft, and 267 ft, respectively. The beds of Great Bear, Great Slave and other lakes are unfrozen.

Two theories may account for the presence of an unfrozen zone separating the permafrost from the active layer: 1) that the permafrost below the unfrozen zone is a relic of past harsher climate and that the present climate is not severe enough to form permafrost; and 2) that the unfrozen zone may be a recent aquifer developed on or near the top of permafrost, in which freezing of the active layer may compress the aquifer, giving rise to hydrostatic pressure that prevents its water from freezing, even when its temperature falls below 0°C. The second theory is unlikely because it is hard to imagine that ground water could force its way through already frozen soil to form such unfrozen zones. However, some unfrozen zones may result from the failure of permafrost to form in aquifers having a high mineral content. A map shows the distribution of permafrost in Canada.

Kamenskii, G. N. (1947) "Hydrogeological Investigations of the Sources of Water Supply Under Permafrost Conditions," <u>Poiski i Rasvedka Podzemnykh</u>
<u>Vod: Moscow-Lenigrad, Gosgeolizdat</u>, Chapter 6, pp. 196-201 and pp. 281-283

Abstract

Prospect drilling for water in ground having negative temperatures is complicated by freezing of the drilling tools in the hole; this problem can be eliminated by using heated water, steam, and brine sollutions during drilling. Systematic measurement of temperatures should be made during drilling, either with slow-recording or electric thermometers, in order to determine the depth of the lower boundary of permafrost and the presence of talik, as shown by positive temperatures. Test-pumping experiments are made to determine the efficiency and reserves of ground-water reservoirs.

Of the various types of suprapermafrost water, that confined in thick alluvial deposits which do not completely freeze in winter is of significance. Yield of suprapermafrost waters is subject to fluctuation

Throughout the year, and the maximum and minimum yield must be determined by research work. Determination of maximum production is made during the summer when thawing is at its maximum pumping is done by using the "Tim method" (Thiem?) in conjunction with calculations of the distribution of flow, or by practical exploration methods of interaction of drill holes. In summer, it is important to consider influence of surface water on productivity of aquifers, especially those connected hydraulically with rivers. Determination of minimum flow is made during the maximum freezing period in late winter when the weak suprapermafrost supplies freeze; even the better aquifers are reduced to a minimum. Test pumping in this case must be prolonged 10 to 15 days, or even 1 to 2 months. Under these conditions recharge of the aquifer is stopped and the reserves diminished. The estimate of reserves should not be based solely on the natural distribution of flow, but on the measure of temporary reserves that are recharged during the period of summer thawing. Methods of test pumping of suprapermafrost waters for productivity are the same as for artesian waters and shallow aquifers. Investigations are recommended of icings and hydrolaccoliths originating from subpermafrost and suprapermafrost waters. The flow of water that forms icings can be determined by measurements of the volume of ice. Information on the thickness of permafrost is given, and the increase in temperature is cited as 1°C per 100 m depth in permafrost regions.

Mining operations are commonly facilitated by permafrost which maintains stability. However, in the Amderma region, the mines are infiltrated by salt water which has a temperature of $-5\,^{\circ}\text{C}$ near the surface. The permafrost layer, about 400 m thick, has a temperature of $-4.8\,^{\circ}\text{C}$ at a depth of 215 m. Comparison of chemical analyses of sea water and water from mines near the coastline shows that salt water will penetrate permafrost layers and hamper mining operations.

Krynine, D. P. and W. R. Judd (1957) "Principles of Engineering Geology and Geotechnics," McGraw-Hill, New York-London-Toronto, p. 730

Abstract

Ground water above permafrost in summer may be a limited source of supply, but because of its shallowness, it is subject to contamination and commonly disappears in winter. If the active layer is in impervious materials, ground water trapped between the active zone and permafrost may move horizontally to contribute to formation of hydrolaccoliths, or it may form a conduit through the active zone or appear in thawed zones beneath heated buildings or along streams and abandoned stream channels.

Water within permafrost occurs in alluvium near rivers, abandoned river channels, or in thawed gravel beds, and even in thawed areas between masses of permafrost, near standing water, on south-facing hillsides, and where vegetation has been stripped.

Water below permafrost occurs in large quantities and generally satisfies sanitary requirements; it is located in alluvium beneath permafrost and in joints and other space in bedrock. In hilly regions water under permafrost may be under high pressure and flowing wells may result.

Icings formed at points of ground-water emergence upslope from places where deep freezing has taken place can be controlled by construction of frost belts at some distance upslope from the road or other structure. Icings may be controlled also by ice fences and heating.

Law, James (1971) "Regional Devonian Geology and Oil and Gas Possibilities, Upper Mackenzie River Area," <u>Bulletin of Canadian Petroleum Geology</u>, Vol. 19, No. 2, pp. 437-486

Abstract

The upper Mackenzie River area is homoclinal in the east, with broad gentle uplifts. In the west there are large anticlines and thrust faults.

Devonian sediments thicken westwards from zero to over 10,000 ft. Early Devonian carbonates of the Delorme, Camsell and Sombre formations are present in the west. Early Eifelian rocks consist of basinal shales and limestones of the Funeral Formation and dolomites of the Arnica and Manetoe formations in the west, and evaporites of the Bear Rock and lower Chinchaga formations in the east. Late Eifelian rocks consist of Hume, Headless and lower Nahanni limestones and shales in the west and upper Chinchaga evaporites in the east. The name Willow Lake Formation is proposed for the dolomites lying between the lower Hume and the upper Chinchaga, and the name Ebbutt Member is proposed for the terrigenous clastic unit occurring at the base of the Willow Lake and extending into the basal Hume and middle Chinchaga.

Givetian rocks are mostly limestones and shales with important reef developments in the upper Nahanni and Kee Scarp carbonates. A major uplift, the Upper Mackenzie River Uplift, which affected most of the area, caused thinning of the early Givetian, upper Nahanni limestones and Horn River shales, and may have caused a mid-Givetian unconformity.

Upper Devonian rocks consist of shales with subsidiary silstones, sandstones and limestones.

Many anticlinal, reef and stratigraphic pinch-out traps remain to be tested.

Lebedev, A. F. (1936) "Soil and Ground Waters," Akad. Nauk SSSR Izd., Moscow, p. 314

Abstract

Old and new theories of ground-water formation are summarized and discussed. The laws of free, oriented and bound water migration in the soil both up and down are discussed. Problems of soil moisture accumulation and the role of evaporation and condensation of water in the formation of ground ice in permafrost are explained. The soil

composed of solid or loose rock strata, frozen or unfrozen, is always porous to water vapour to a certain degree. Water condensing in permafrost in the form of ice layers comes from lower strata where vapour pressure is greater.

Levinson, A. A., Brian Hitchon and S. W. Reeder (1968) "Major Element Composition of the Mackenzie River at Norman Wells, N.W.T. Canada," Geochemica et Cosmochimica Acta, Permagon Press, Vol. 33, pp. 133-138

Abstract

The Mackenzie River at Norman Wells (about 88 per cent of the total Mackenzie drainage) has an average annual flow of 306,000 cfs, with great seasonal variations, and a discharge-weighted average dissolved solids content of 173 ppm which varies seasonally in the narrow range of 162-176 ppm. The previously observed chemical similarity between the Mackenzie and the Mississippi is confirmed.

MacKay, B. R. (1945) "Canada's Ground Water Resources from a Geological Aspect,"
American Water Works Association Journal, Vol. 37, pp. 84-100

Abstract

This introduction to the report is a statement of the past studies of the Water Supply and Borings Section, Geological Survey of Canada, the materials available for study, and a sketch of the physiography and geology of Canada. Most of the ground water utilized comes from unconsolidated deposits.

Canada is divided into three major structural units, the Laurentia, Cordillera, and Appalachia units, which are subdivided into stratigraphic units, and further subdivided into ground-water provinces. Permafrost is mentioned in discussion of certain units and provinces, as follows.

In the Arctic Islands Paleozoic ground-water province, the glacial drift is frozen, and water supplies are developed from either streams or wells that penetrate the frost zone into underlying bedrock. In the Arctic Islands Mesozoic province, water could be obtained from porous sandstone aquifers below the frostline. The Appalachia structural unit lies south of the permafrost zone, and the Cordillera unit is not subdivided.

MacKay, J. R. (1955) "The Anderson River Map-Area, N.W.T.," <u>Canada Department</u> of Mines and Technical Surveys, Geographical Branch Memoir 5, p. 137

Abstract

Even though the area lies within the permafrost zone, underground drainage occurs. In 1951 underground drainage was observed passing through a sand and gravel terrace near Rummy Lake, and the flow, in the form of perennial springs, fed a creek that built an ice fan each winter. The source of the flow was probably a lake a few hundred yards away. Another example of drainage through sand and gravel was

seen on July 4, 1951, on the east side of Stopover Lake near the source of Horton River. The entire flow of a stream 10 ft. wide and several inches deep discharged into a lake 100 ft. across. The lake had no outlet, but conical pits in the bottom were seen to be the places through which water drained into the ground.

Ground ice in the region forms tundra polygons like those described by Leffingwell (1919) and Black (1953); the broad ice wedges are 5-10 ft across and probably go down 20-30 ft or more. Some ice wedges in permafrost extend below sea level. Polygons in the tundra flats bordering the old channel leading from Horton River to Harrowby Bay are hardly more than 150 years old, and some are younger because they have kept pace with continuous infilling of the channel. Pingos occur at the foot of Parry Peninsula, 4 miles south of Langton Bay, at 68°13' N. 122°35' W. and at 69°3' N. 120°15' W.; they are as much as 150 ft high. In 1955, storm waves intersecting a pingo on the east side of McKinley Bay exposed the core of clear white bubbly large-crystalled ice which was overlain by 4-5 ft of brown sand, locally containing small clam shells.

Moore, E. W. (1949) "A Summary of Available Data on Quality of Arctic Waters," National Research Council, Division of Medical Science Report to Subcommittee on Water Supply of the Committee on Sanitary Engineering and Environment, p. 14

Abstract

Wells in Yukon Territory, Canada, near rivers yield water of good Quality; those in permanently frozen ground freeze up in winter and cannot be relied on for permanent water supplies. Analyses of ground water from sandpoints in permafrost near Mayo and from a shallow well near Klondike River (Dawson area) show, respectively, 132 and 148 ppm dissolved solids, including 0.07 and 0.02 ppm iron.

Analyses of shallow ground water in permafrost regions of Northwest Territories, Canada, are given for Fort Resolution and Sawmill Bay, and other sites in which total calculated dissolved solids range from 486.7 to 3,600 ppm. The waters are hard and contain much iron; they contain organic matter, ammonia, and albuminoid nitrogen. Wells in permafrost seem to be unreliable in both yield and quality of the water.

Analyses of ground waters at Ladd A.F.B. (well 6), Tanana, Anvik, and Sinuk, Alaska, are given; dissolved solids range from 178 to 458 ppm, including iron content of 0.03-11.8 ppm. The waters are apparently moderate to high in hardness and mineralization.

Norris, D. K., R. A. Price and E. W. Mountjoy (1963) "Geology, Northern Yukon Territory and Northwestern District of Mackenzie," Geological Survey of Canada Map 10-1963

Abstract

Map showing geology of Northern Yukon Territory and Northwestern District of Mackenzie.

"Northwest Territories and Yukon Territory, Schedule of Wells, 1965,"

Department of Indian Affairs and Northern Development Schedule

No. 5, p. 59

Abstract

The Fifth Schedule of Wells, compiled and annotated by Officers of the Resource Management Division, is alreport of all wells drilled and completed in the Yukon and Northwest Territories, from 1920 to the end of 1965. Pursuant to Section 107 of the Canada Oil and Gas Land Regulations, the information contained is compiled from Well Completion Data Forms, and released from confidential status two years after the completion or abandonment of an exploratory well, and thirty days for a development well. Basic information on wells such as location, elevation and depth is released at any time. Further details on non-confidential wells and structure test holes can be obtained at the office of the Oil Conservation Engineer in Calgary.

Ponomarev, V. M. (1956) "The Main Characteristics of Ground Water Formation in Permafrost Regions," <u>Tezisy i Plany Dokladov -- k Soveshchaniiu 1956 g. Merzlotovedeniiu</u>, Akad. Nauk SSSR. Inst. Merzlotoveneniia, No. 2, pp. 29-32

Abstract

The characteristics of ground-water circulation, exchange, and chemical composition in permanently frozen rock are discussed. These types of water are distinguished: fresh water at the surface, saline water in the middle layer, and water vapour in the bottom zone. The distribution of ground water in permafrost in given areas is closely related to their Quaternary history. Areas of young rock folds correspond to areas of the most intense ground- and surface-water exchange, plateaus to those of medium water exchange, and lowlands to those of very weak water exchange. Surface water forms the waterbearing horizon of the active layer and remains in the liquid state only a limited period of time, while ground water above the local erosion level is usually always frozen. The upper artesian water horizons in the north are frozen, while the temperature of those in large geological basins is depressed. Artesian water supply occurs through unfrozen areas under rivers, lakes, and along tectonic faults. In north coastal regions the ground water is high in marine mineral content and is in constant motion due to geothermal gradients.

Ponomarev, V. M. and N. I. Tolstikhin (1959) "Ground Water in Permafrost Areas," Osnovy Geokriologii, Pt. 1, Chap. 10, Akad. Nauk SSSR, Inst. Merzlotovedeniia, pp. 328-364

Abstract

The origin and characteristics of ground water in permafrost areas and their interaction with the permafrost are discussed in detail. The various types of ground and artesian waters are described individually, and a table is presented giving for each type the state of the water (whether liquid or solid), its temperature, pressure, quality, mode of alimentation, and possible use. A map showing the distribution of various types of ground water in the permafrost regions of the USSR is included.

Porfir'yev, M. M. and G. V. Porkhayev (1963) "Utility Networks in Permafrost Regions," Proceedings: Permafrost International Conference, National Academy of Sciences -- National Research Council, Publication No. 1287, pp. 455-458

Abstract

The severe climate in permafrost areas makes it necessary to provide maximum comforts for human habitation. Therefore, all modern facilities -- water works, sewerage, central heating, power, as well as gas supply in a number of localities -- are widely used. In some areas where natural fuels are scarce, all domestic needs, including heating systems, are electric.

The main problems in designing utility nets are dependability and continuous operation. Accordingly, their design and operating conditions must be chosen to prevent damage to the networks by soil subsidence after thawing, heaving, frost cracks, icing, and solifluction processes, and to preclude the possibility of freezing of fluids in pipes.

Reed, I. McK. (1943) "How Dawson Keeps its Water Mains from Freezing," <u>Pacific Builder</u> and Engineer, Vol. 49, No. 8, p. 54

Abstract

Water for Dawson, Yukon Territory, is obtained from a well, supplemented at extra demand from the Klondike River.

Sargent, Charles (1963) "Water Works Supply Systems in Permafrost Areas,"

Proceeding: Permafrost International Conference, National Academy of
Sciences -- National Research Council, Publication No. 1287, pp. 440-441

Abstract

Abundant potable water is necessary to comfortable living in any environment; a population's health depends on pure water for all domestic uses, and almost any modern industry uses water in quantities equal to or exceeding the tonnage of its product. Civilization cannot thrive where an adequate supply of good water cannot be made available.

In about one-fifth of the land area of the world, the ground remains at a temperature below the freezing point of water throughout the year. Where such a condition exists, the area is classified as a permafrost area in this paper, regardless of whether ice exists in the ground.

Industrial, commercial, or domestic habitation of permafrost areas requires special consideration of water supply and distribution problems beyond those necessary in more temperate areas. The water source may be frozen, water may freeze in the distribution system, or both. Available water may be of such poor quality that special conditions must be considered for its treatment. The availability of a water supply may be the greatest single factor in selecting community sites in permafrost areas.

Schultz, J. R. and A. B. Cleaves (1955) "Geology in Engineering," John Wiley and Sons, New York, p. 522

Abstract

In permafrost regions of the northern hemisphere ground water is the best source of supply in the south, but ground water becomes increasingly difficult to obtain in the north, where permafrost attains great thickness. The water that lies above permafrost is called suprapermafrost water and is fed by rain and melt water, surface water, water condensed by contact with the cold ground surface, and seepage from within or below permafrost. A year-round supply is available only in the parts of the suprapermafrost zone in which permafrost lies below the depth of seasonal frost penetration, particularly along banks of large rivers and lakes with constant inflow and outflow; supplies may occur also at the mouths of valleys and at the heads of alluvial fans. Suprapermafrost water is subject to contamination. In winter the ground freezes from the top downward and the water is subjected to pressure, with the result that water emerges at the surface to form icings or is wedged between frozen and unfrozen layers and frozen in place to form ground ice.

Intrapermafrost water is derived from sources above and below the permafrost. It occurs mainly in thick alluvial deposits near rivers, in old river channels, and, to a lesser degree, in strongly fissured and jointed rocks. Along the Arctic Coast saline water within the permafrost is probably of marine origin; such mineralized water remains liquid at temperatures well below 0°C. Care must be taken to maintain circulation of intrapermafrost water in permeable layers or in pipelike openings, for freezing will result if flow is retarded or if the well is subjected to excessive or accelerated pumping. Intrapermafrost water may locally be under pressure.

Subpermafrost water is always liquid, being beneath permafrost, and is generally under considerable hydrostatic pressure. It furnishes the most dependable supply of ground water, usually of good quality. In some areas, however, subpermafrost water is highly mineralized. Generally, it is difficult to locate because of scarcity of surface indications.

In addition to the discussion of ground water in permafrost regions, a description of pingos, frost blisters, icing mounds, and peat mounds are included in this publication.

Silin-Bekchurin, A. I. (1951b) "Methods Employed in Studying Underground Waters in Permafrost," Spetsial'naia Gidrogeologia: Moscow, Gosgeolizdat, pp. 277-280

Abstract

Methods for selecting and drilling for water supply in permafrost regions are described. Drilling for suprapermafrost water is similar to the methods used under nonpermafrost conditions. Test drilling for subpermafrost water in alluvial deposits should be placed near the river channel and extended into areas receiving maximum insolation. Drilling should be started wherever seepage of water from alluvial deposits occurs. Drill holes should be placed from 50 to 200 m and should be arranged in a checkerboard pattern. Test drills in stratified bedrock should be placed along and across the axis of the syncline depending on the structure of the bedrock. The deepest water vein should be tapped for relatively warm water whenever several veins are available.

Sumgin, M. I., N. N. Geniev and A. M. Chekotillo (1939) "Water Supply of Railroads in Permafrost Regions," Moscow, Transzheldorizdat, p. 251

Abstract

The book contains chapters on thermophysics, thermodynamics of the ground, permafrost, water sources, methods of investigating water sources, organization of water-source studies, water-intake structures, construction of water-conduit network, thermal technique for the water system, laying pipe during winter, supplementary structures for water conduits, thermometry, experimental determination of heat loss in water lines and thermal regime of an operating water-supply system.

Outlets of subpermafrost water are found along the boundaries of different rock strata and along faults. Locating these narrow zones in the subsurface by drilling is difficult, and it is usually done by developing the surface seepages. The best time to prospect for springs is February or March when they can be recognized by icings and icing mounds. The water outlet may be determined approximately by the direction of the flow of the water and by an increase in temperatures toward the source. Water source is usually located at the uphill edge of icings. Taliks are usually found by shallow drill holes; decreased thickness of seasonal frost and greater depth to permafrost may indicate the proximity of a spring. Discharge of the spring is concentrated in channels and measured, or is estimated from the volume of the icing divided by 100 days the time usually required to form ice up to early March in the region under study.

A more detailed study of the springs specifies the geologic conditions of the water outlets for correct construction of the spring capping, makes a more precise discharge measurement during various seasons, and determines the quality of water. During this stage further drilling and test-pitting are done to define the contours of the talik in which the spring occurs.

"Summary Report, 1921, Part B" Geological Survey of Canada No. 1959, p. 104

Abstract

This publication contains several reports and maps covering the geology of the Mackenzie River Valley Region.

Tassonyi, E. J. (1969) "Subsurface Geology, Lower Mackenzie River and Anderson River Area, District of Mackenzie," <u>Geological Survey of Canada Paper 68-25</u>, 207 pp.

Abstract

This report deals with the subsurface stratigraphy of the Mackenzie River region between 64 degrees north latitude and the Arctic coast, and between the Canadian Shield and the west border of Yukon Territory. The study is based on the examination of well samples, cores, and mechanical logs of all important exploratory wells drilled prior to March, 1961, and on published information to that date. References are made to surface geology and paleontology, and to published stratigraphic concepts in order to substantiate the suggested nomenclature and stratigraphy. Several informal lithologic units and one new formation are introduced. The economic potential of each formation (principally with regard to hydrocarbon production) is examined.

The Macdougal Group comprises: (1) the Mount Clark Formation consisting of red sandstone, red shale, ferruginous sandstone and hematite; (2) the Mount Cap Formation consisting of green and red sandstone with some rusty shale; and (3) the Saline River Formation consisting of red and green shales with salt casts. It includes Lower and Middle Cambrian rocks and probably includes Upper Cambrian strata as well. A disconformity between this group and the overlying beds is postulated.

At some places within the study-area the Macdougal Group is overlain by stratigraphic equivalents of the Franklin Mountain Formation. In the subsurface study the exact stratigraphic equivalents of the Franklin Mountain Formation could not be recognized but are probably included in the upper part of the Saline River Formation and lower part of the Ronning Formation.

The Ronning Formation, as defined in this report, includes strate equivalent to the Mount Kindle Formation and part of the underlying Franklin Mountain Formation but the detailed relationships between these units are not yet known. In the subsurface the Ronning Formation consists principally of dolomites. It overlies the shaly, semievaporitic facies of the Saline River Formation with assumed disconformity and is considered, tentatively, to be Early Ordovician to Late Silurian in age.

The Ronning Formation is overlain disconformably either by the Early and Middle Devonian (Eifelian) Bear Rock Formation consisting of brecciated dolomites and interbedded evaporites or by equivalent strata within the Gossage Formation composed of non-brecciated, bedded limestones and dolomites. In the study-area, the Bear Rock Formation (restricted) grades laterally into the Gossage Formation. In the subsurface, the Bear Rock Formation is divided informally into a lower, evaporitic member and an upper, brecciated member. The Gossage Formation comprises three informal members.

The Hume Formation of Middle Devonian age, consisting of fossiliferous limestones with some shale, overlies the Bear Rock or Gossage Formations. The upper contact with the Hare Indian Formation is abrupt but conformable, whereas the lower contact is probably disconformable.

Overlying the Hume limestones is the Hare Indian Formation which is divided informally into two members. The lower, or spore-bearing member, consists of dark brown to black, bituminous shales containing trilete spore cases. The upper, unnamed member of the formation, is composed of grey to green, calcareous shales with interbedded, thin, limestone beds.

Within the overlying Ramparts Formation two informal members are recognized: the lower, or platform member, consists of fossiliferous, bedded, brown and grey, argillaceous limestone, and includes at the top the shaly Carcajou marker; the overlying reef member consists of massive, clean, grey to buff limestone characterized by corals and stromatoporoids. A Givetian (Middle Devonian) age has been accepted with reservation for this formation.

The Ramparts beds are overlain unconformably by the Canol Formation, which is composed of about 75 feet of dark grey, greenish and yellowish weathering, non-calcareous shales. A tentative Upper Devonian (Frasnian) age is assigned to this formation.

In the study-area, the Imperial Formation includes all Upper Devonian shales, siltstones and sandstones overlying the Canol Formation and overlain unconformably by Cretaceous strata. It is divided informally into a lower member of Frasnian and Fammenian ages.

The presently accepted Cretaceous formations comprise the following in ascending order: (1) the Sans Sault Formation, consisting of marine sandstone and shale; (2) the Slater River Formation, consisting of dark grey to black shale with ironstone concretionary layers and thin bentonite bands; (3) the Little Bear Formation, comprising sandstone, sandy shale, conglomerate and coal; and (4) the East Fork Formation, composed mainly of dark grey, marine shale.

In the wells studied, the youngest Cretaceous formation, the East Fork Formation, is missing and the Little Bear Formation is incomplete. In the subsurface, division and correlation of the Cretaceous strata is attempted by using the described surface formations. This is considered

to be tentative until such time as Cretaceous stratigraphy is revised through surface studies.

Tertiary sands, gravels, shales and lignites overlie the Cretaceous East Fork Formation locally. In the subsurface medium-grained, porous, friable sandstones and silty shales are tentatively assigned to the Tertiary.

Coal seams have been reported from the Cretaceous and Tertiary strata but are of little economic value at this time. No coal or lignite seams are present in the examined wells, either in the Cretaceous or in the tentatively identified Tertiary strata.

Halite occurs in the Cambrian but the depth and location of the occurrences make its recovery prohibitive at this time. There is no indication of potassium salts and reported gypsum occurrences are too impure to be commercial.

The primary economic interest in the study-area has been and remains the exploration for oil and natural gas and the potential for these minerals appears to be greater than for any others. At present, oil and gas are being produced only from the reef member of the Ramparts Formation although other formations have productive potential.

Thomas, J. F. J. (1956) "Interim Report-Hardness of Major Canadian Water Supplies," Canada Department of Mines and Technical Surveys, Mines Branch, Memo. Series 132

Abstract

Report includes data on Dawson, Yukon River, Whitehorse, Aklavik, and other places in the permafrost zone.

Wilson, J. D. (1949) "Arctic Construction," Military Engineer, Vol. 41, pp. 258-260

Abstract

Permafrost underlies much of the Arctic from depths of a few feet to as much as 700 ft. Permafrost can exist where mean air temperature is only a degree or two below freezing. Ground water may exist above, within or below permafrost. Practically all destructive effects of freezing and thawing are related to ground water. Heat is conveyed by ground water to thaw permafrost. Ground water may be present, at all seasons, between the permafrost table and the base of seasonal frost.

Williams, John R. (1970) "A Review of Water Resources of the Umiat Area, Northern Alaska," U.S. Geological Survey Circular 636, p. 8

Abstract

Surface-water supplies from the Colville River, small tributary creeks, and lakes are abundant in summer but limited in winter by low or zero flow in streams and thick ice cover on lakes.

Fresh ground water occurs in unfrozen zones in alluvium and in the upper part of bedrock beneath the Colville River and beneath lakes that do not freeze to the bottom in winter. These unfrozen zones, forming depressions in the upper surface of permafrost, are maintained by flow of heat from bodies of surface water into subjacent alluvium and bedrock.

Brackish or saline ground water occurs in bedrock beneath as much as 1,055 feet of permafrost in the Arctic foothills and beneath 750 to 800 feet of permafrost beneath low terraces of the Colville River valley. The foothill area is unfavorable for developing supplies of potable ground water because of the great depth to water, predominance of brackish or saline water, and low potential yield of the bedrock. In the Colville River Valley, shallow unfrozen alluvium beneath the river and deep lakes will yield abundant year-round supplies of ground water, but the bedrock below permafrost yields less than 10 gpm (gallons per minute) of saline or brackish water.

Williams, John R. (1970) "Groundwater in Permafrost Regions of Alaska," U.S. Geological Survey Professional Paper 696, p. 83

Abstract

Although ground water 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 ground-water flow systems. Frozen ground is an impermeable layer which: (1) Restricts recharge, discharge, and movement of ground water, (2) acts as a confining layer, and (3) limits the volume of unconsolidated deposits and bedrock in which liquid water may be stored. Frozen ground in many areas eliminates shallow aquifers and requires that wells be drilled deeper than in similar geologic environments having no permafrost. Although little is known about the effect of permafrost and low water temperatures on quality of ground water, the restricted circulation imposed by permafrost boundaries may increase the concentration of dissolved solids in ground water in some areas. Low ground temperatures above and below permafrost result in groundwater temperatures ranging from 0° to 4.5°C (Celsius). At these temperatures, ground water is more viscous and moves more slowly than in temperate regions.

Permafrost is defined as unconsolidated deposits of bedrock that continuously have had a temperature below 0°C for 2 years to thousands of years. It formed when the balance between net heat lost to the atmosphere at the surface and that received from sources within the earth produced

Williams, M. Y. (1922) "Exploration East of Mackenzie River, between Simpson and Wrigley," <u>Canada Geological Survey Summary Report</u>, 1921, Part B, pp. 56 - 66

Abstract

The soil is generally frozen in the area. Mineral springs occur near Old Fort Wrigley where water issues from the surface of the smaller island 15 ft above river level and leaves a deposit of lime. Lime deposits also occur on the mainland across the river. Mineral springs occur also at Roche-qui-trempe-a-l'Eau, where warm waters emerging from a travertine cone about 50 ft above the river have deposited calcareous material. The springs are related to a fault.

Yates, A. B. and D.R. Stanley (1963) "Domestic Water Supply and Sewage Disposal in the Canadian North," <u>Proceedings: Permafrost International Conference</u>, National Academy of Sciences - National Research Council Publication No. 1287, pp. 413 - 419

Abstract

This paper deals with water supply and sewage disposal in the Yukon and Northwest Territories of northern Canada. These cover 1,511,979 square miles or 39.3% of the total Canadian land and water mass, lie above 60° latitude, and are populated as far north as Alert at the 83° latitude.

The problem of water supply and sewage disposal in northern Canada is twofold: First, to obtain adequate water supplies for drinking, culinary, and minimum sanitation requirements and dispose of human waste, garbage, and wash water in a satisfactory, sanitary manner. Second, to provide modern water and sewerage systems so that inhabitants can enjoy normal amenities at reasonable cost.

Zoltai, S. C. and C. Tarnocai (1971) "Properties of a wooded palsa in Northern Manitoba," <u>Arctic and Alpine Research</u>, Vol. 3, No. 2, pp. 115 - 129

Abstract

A palsa complex, 106 m in diameter, having a maximum height of 224 cm above the water table is described in detail. Permafrost occurred under the elevated, densely wooded palsa, extending into the underlying clay. The height of doming was largely due to ice accumulation in the clay and peat. The thickness of the active layer was least under the densest black spruce stands and greatest in the openings. The cumulative depth of snow was greatest in openings and least in dense stands. The volumetric moisture content of the peat in the active layer was about 30% in the fall, but this figure nearly doubled in the winter; the moisture content of the frozen core remained constant at over 90%. The peat material was largely mesic sedge peat near the bottom with mesic forest peat closer to the surface.

Mackay, J. Ross (1966) "The Mixing of the Waters of the Liard and Great Bear Rivers with those of the Mackenzie," Geographical Bulletin, Vol. 8, No. 2, pp. 166 - 173

Abstract

The interpretation of temperature and Secchi disk transparency readings for the right and left banks of the Mackenzie River below its junction with the Liard at Fort Simpson, N.W.T. are discussed. The measurements, made in 1963 and 1964, were taken in June after break-up. In both years the results show that, 200 miles downstream, the warmer and more turbid waters of the Liard had not fully mixed with those of the Mackenzie. Similarly, a study of the Great Bear River below Fort Norman, N.W.T. shows that the mixing of its waters with those of the Mackenzie was not fully completed 50 miles below their confluence.

Dingman, S. L., H. R. Samide, D.L. Saboe, M.J. Lynch & C.W. Slaughter (1970)

"Hydrologic reconnaissance of the Delta River and its drainage basin, Alaska."

U.S. Army Cold Regions Research and Engineering Laboratory, Research Report

262, 81 pp, 22 tables, 74 refs, appendices, map.

Abstract

Estimates of the water balance, flow duration curves and sediment characteristics of this large braided glacial river are reported. The catchment is 1665 square miles in the east central part of the Alaska Range. The general geomorphology of the basin is outlined and references to further studies are given. Of the mean annual precipitation of 40.4" (the mean annual loss of permanent storage is about 1") some 30% leaves as evapotranspiration, 50% as stream flow and 20% as groundwater flow. Characteristics in the response to glacial melt are outlined. Peak flow at foothill stations occurs within 24 hours of the rainfall if greater than 0.5"/day - amounts less than this do not generally produce a measurable stream response. The stream geometry is described in detail and the response to glacial melt and rain, channel geometry and processes are described. Lower floodplain channels are asymmetric and roughly triangular or parabolic and have a high width/depth ratio. Gauging station hydraulic geometry is described together with channel changes.

APPENDIX 'J'

USE OF DRILLSTEM TESTS TO INTERPRET THE GROUNDWATER FLOW SYSTEM

Dr. R. O. van Everdingen, Groundwater Subdivision, Inland Waters Branch, Environment Canada, provided us with a computer record of drillstem tests run by oil companies. They represent data on non-confidential boreholes located in the general Mackenzie River Valley region. Data available on individual boreholes include borehole location, elevation, variations in water quality and temperature with depth, hydrostatic head from shut-in pressures, formation age, stratigraphy, and lithology.

Using these data we plotted five cross-sections showing hydrostatic heads, total dissolved solids, and the geological formations penetrated in the drill holes. Two generalized cross-sections — one located near Camsell Bend and the other near Norman Wells — have also been constructed to show the regional ground—water-flow pattern. A few tentative conclusions are suggested from analysis of the limited data available:

The groundwater flow system appears to conform to the generally accepted theory that groundwater recharge occurs in highland and mountain regions and that groundwater discharge occurs in lowland regions, which in the present study-area comprises the Mackenzie River Valley and its main tributaries. Data contained in Appendix 'A' deal with evidence of groundwater discharge; they suggest that most groundwater flow discharges into the Mackenzie River. From examination of Figs 15 and 16, it would appear likely that the Franklin Mountains on the east side of the Mackenzie River Valley present an obstacle to groundwater flow to the northeast and to the Precambrian Shield. We believe that the existence of the Franklin Mountains lying to the east of the Mackenzie Valley is the main reason that most groundwater west of the Mackenzie River discharges into that river valley -rather than discharging along the margin of the Precambrian Shield to the On the other hand, any groundwater recharge on the east side of the Franklin Mountains does in all likelihood discharge along the margin of the Precambrian Shield. Similarly, groundwaters in relatively gently dipping strata south and southwest of Great Slave Lake probably flow toward that major water body.

- 2 The groundwater flow system is markedly influenced by differences in permeability between different rock types -- for example, tight shale strata versus highly permeable zones in the Bear Rock Formation. In the generalized Camsell Bend cross-section (Fig 15), the Bear Rock Formation is interpreted as a major regional drain. Unfortunately we have not been able to identify the Bear Rock Formation in any of the drillstem tests. Most of the drillstem tests were run on Devonian Formations considered to offer better oil-bearing prospects. Consequently, the groundwater-flow pattern in detail in any area is far from complete and clear.
- 3 Groundwater qualities generally become more saline with increasing depth and with increasing age of geological formations. An exception, which probably can be attributed to the local groundwater flow system, can be seen on cross-section D-D' near Wrigley, where the deepest water in two boreholes is less saline than it is in a zone immediately above. Cross-section B-B' near the Arctic Red River also shows surprisingly good quality water to depths of 2000 feet.
- 4 Groundwater temperatures have not been included on the cross-sections. We were not able to arrive at any firm conclusion concerning the significance of the temperature values reported. Considerably more study is required to make a valid assessment. However, one might suspect that the high water temperatures at depth represent a potential source of thermal energy for the Mackenzie River Valley region. An attempt was made to arrive at a probable geothermal gradient; but the values studied were too erratic and scattered.

One water temperature observation at a depth of about 11,000 ft in a borehole extending below the Mackenzie River Delta was reported to be 71° C whereas another water temperature at a depth of 7000 ft below ground surface along the Northwest Territories - British Columbia boundary was reported to be 121° C.

LIST OF FIGURES

Figs 1 to 13	Aerial photographs showing prospective site-areas and related research projects
Fig 14	Key map to cross-sections illustrating generalized stratigraphy and inferred regional groundwater flow system
Fig 15	Camsell Bend area cross-section showing generalized stratigraphy and inferred regional groundwater flow system
Fig 16	Norman Wells area cross-section showing generalized stratigraphy and inferred regional groundwater flow system
Fig 17a	Key map to deep boreholes showing stratigraphy, static water levels, total dissolved solids, and hydraulic gradient
Fig 17b	Legend for Figs 18 to 22, inclusive
Figs 18 to 22	Deep borehole logs showing stratigraphy, static water levels, total dissolved solids, and direction of hydraulic gradient in borehole
Fig 23	Small-scale map showing location and depth where water sample was taken and total dissolved solids at sample sites in northwestern Alberta
Fig 24	Key map showing physiographic regions along the Mackenzie River Valley, Northwest Territories
Fig 25	Location of 23 generalized surficial geology, 23 surficial hydrogeology and 23 bedrock hydrogeology maps accompanying this report and corresponding National Topographic Series Map-Sheet Numbers
Fig 26	Key map correlating locations of geographic place-names referred to in this report and corresponding 1:250,000 scale surficial geology maps and/or 1:250,000 National Topographic Series Map Sheets
Fig 27	Location of water-well drillhole sites and springs observed in the field in vicinity of Mackenzie River Valley
Figs 28, 29	Plots showing stream discharge versus specific conductance of river waters, showing the influence of groundwater discharge on water quality (mainly for 1971 and for a limited amount of streamflow data)
Fig 30	Changing climate during Wisconsin and Postglacial (Holocene) time compared to present average temperature (after J. Terasmae)



Fig 1. View of Mackenzie River bank opposite Old Fort Point.
Airphoto shows active slides on the riverbank and a spring at "S." Note extensive thermokarst topography on the right side of this airphoto. Melting of ice in exposed subsoils, continual lateral river erosion, and springs all contribute to bank instability. Panchromatic airphoto.



Fig 2. It is suspected that the dark rims around the large lakes seen here represent "new" ice in peat as the near-vertical permafrost face moves in toward the center of the lakes. The "whitish" upland area is a lichen-covered (Cladonia spp.) woodland carrying stunted black spruce. It is a typical lichen-black spruce open woodland, which is commonly underlain by 5 to 15 feet of ice-rich peat. Panchromatic airphoto.



Fig 3. Colour-infrared airphoto showing pinkish-coloured rendition of vegetation around small thermokarst ponds (see arrows). It is believed that the pinkish tones indicate less-stressed vegetation (i.e., a thicker active layer or deep unfrozen ground) and melting around the periphery of these thermokarst features.



Fig 4. Colour-infrared airphoto of the Norman Wells area showing either a thick active layer or deep unfrozen ground a) on frequently-flooded parts of islands in the Mackenzie River channel, b) in the village of Norman Wells, c) along the sides of the airstrip, d) on thin patchy drift overlying limestone near a rock quarry in the upper right. Highly variable ice contents are expected in the former meltwater channel north-northwest of the airstrip. Thickness of active layer and availability of moisture may be correlated here with flooding, man-made disturbances, and differences in subsurface materials.

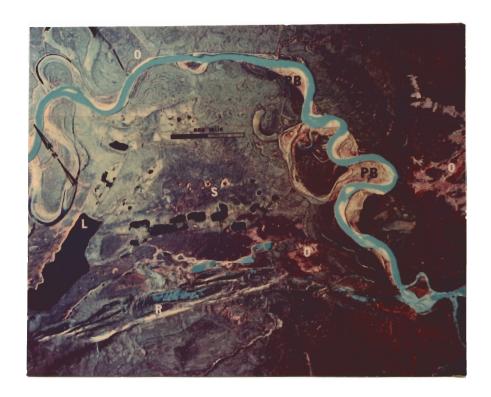


Fig 5. Colour-infrared airphoto along the lower reaches of the Carcajou River showing exposed bedrock (R), vigorous plant growth on outwash ("O" to the right of the river on right side of photo), a thin active layer over thick gravels ("O" north of river), unfrozen alluvium below active pointbars (PB), and narrow rims of thawed ground around small depressions marked "S" and along the side of the lake (L) that is subject to wind and wave action and to a larger input of heat. In this region varying colours on the colour-infrared print are related largely to both type and stressed condition of vegetation.



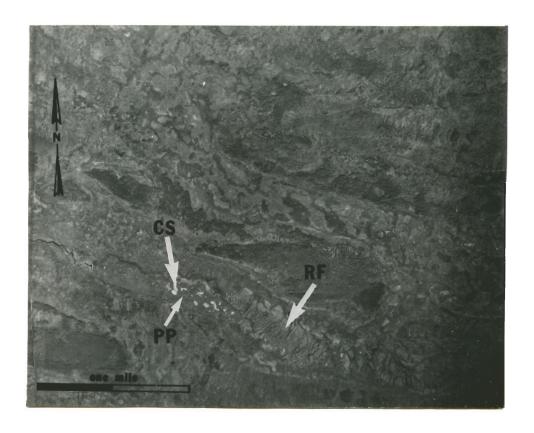
Fig 6. Colour-infrared airphoto showing the marked affect of solar insolation on colour rendition of natural vegetation. Note the light whitish tones of Sphagnum moss and Reindeer lichen in poorly drained areas, and dark pinkish hue on a finger-shaped detachment slide (white arrow to the right of the scale bar). Surface runoff in small creekbeds also has a marked effect on increasing the thickness of the active layer, improving growth conditions and plant vigour. Unfortunately, colour-infrared hues seem to vary somewhat from one area to another, and with laboratory processing as well as with the type of film used. This sensor is most useful as a guide to differences in thermal conditions as reflected by plant type and plant vigour.



Fig 7. Colour infrared airphoto showing brownish olive green hues (<u>see</u> arrows) on wooded portions of ice-rich peat plateaus and whitish speckles in unfrozen treeless collapse scars, which are covered with Sphagnum mosses and heath plants. These colours show up more clearly on the original pictures.



Fig 8. These poorly expressed ribbed fens (RF) in light blue depressions near Bear Rock, north of the Great Bear River, do not show the pinkish hues seen in colour-infrared photographs taken near Fort Simpson using a hand-held camera using colour infrared film. One wonders if the difference is due to depth of unfrozen ground, type of film used, or to laboratory processing. Normally the fens are unfrozen — at least in vicinity of Fort Simpson. However, transitions occur between "true" fens and "true" bogs.



Panchromatic aerial photograph showing frozen ice-rich wooded peat plateaus (PP) with unfrozen treeless collapse scars (CS), and unfrozen ribbed fen (RF) in vicinity of Fort Simpson, N W T. The prevailing ground-water flow (recharge/discharge) system and ground-water chemistry is believed to be different in these two adjoining but different peatland types. This difference in ground-water flow regime and ground-water chemistry may account for the marked differences in permafrost occurrence in these two different peatland types.

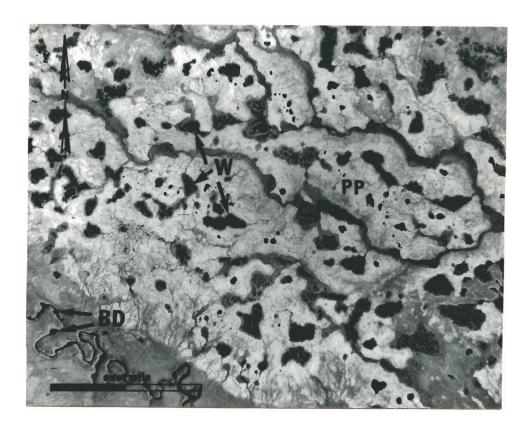


Fig 10. Panchromatic aerial photograph showing beaded drainage (BD) in a region of extensive, thick, stratified, fine-grained glaciolacustrine sediments covered by thick (5 to 15 feet) ice-rich peat in sparsely treed peat plateaus (PP) surrounding unfrozen windows (W) that are believed to be shrinking, rather than enlarging, in size.



Fig 11. Colour-infrared airphoto showing pinkish hues in vegetation (thicker active layer) on a) sand dunes (SD), b) better-drained ridges (lower water table) on the small island, c) frequently flooded margins of islands, d) better drained slopes on Perry Island (large island). Note that, even at this latitude, thermokarst features occur on poorly-drained areas underlain by fine-grained alluvial deposits that are insulated by some 12 to 18 inches of dry peat and ground cover.

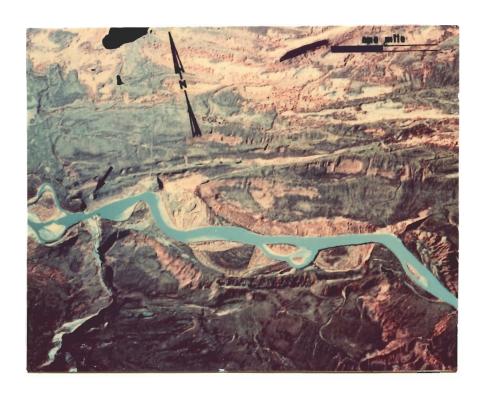


Fig 12. Black arrows on opposite sides of the Carcajou River (about 1½ miles apart) point to small sinkholes in karstic bedrock. These localities might be inspected visually for evidence of groundwater flow and seepages along nearby slopes. Note that both sinkholes appear to be postglacial in age and situated near high river banks. Colour infrared airphoto.

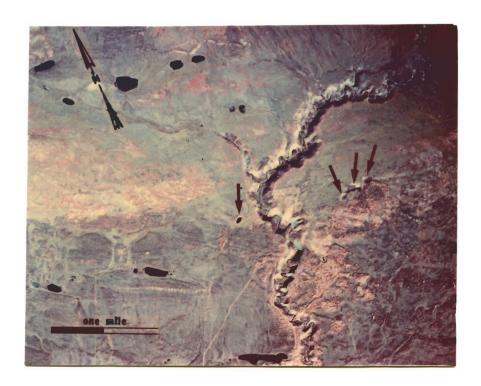
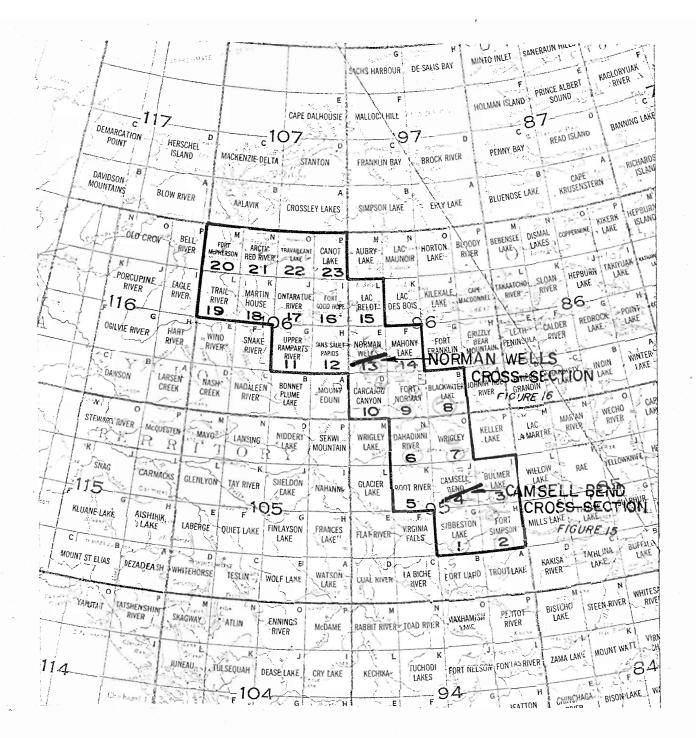


Fig 13. Black arrows point to postglacial sinkholes on opposite sides of Vermilion Creek southeast of Norman Wells. Note the standing water and vertical walls in the sinkhole on the west side of Vermilion Creek.



REGIONAL STRATIGRAPHY AND INFERRED GROUNDWATER FLOW REGIME

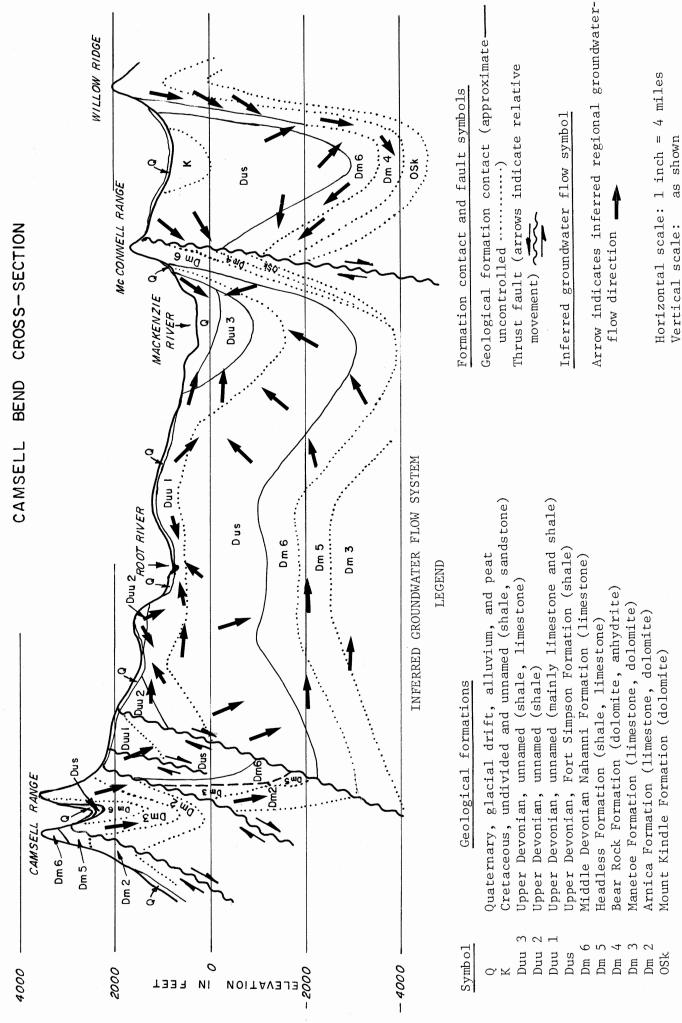
ALONG

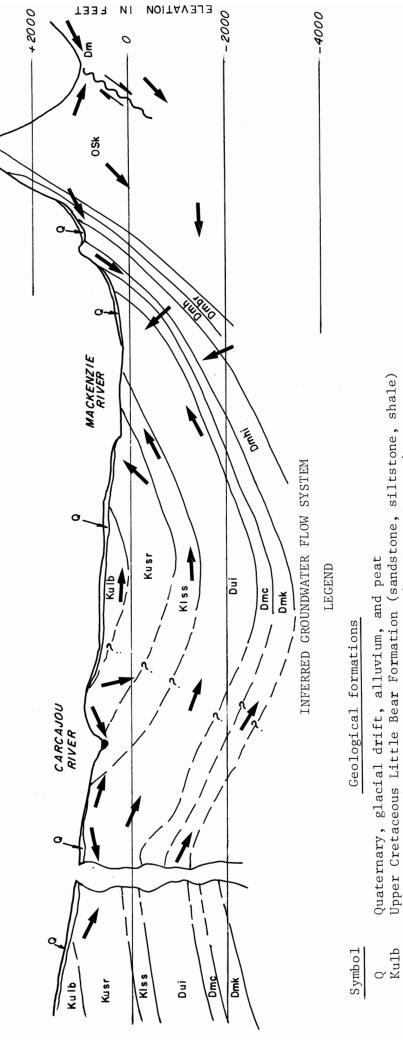
MACKENZIE RIVER VALLEY, N.W.T.

AND

SHOWN IN FIGURES

15, 16





NORMAN RANGE

CROSS - SECTION

NORMAN WELLS

Jpper Cretaceous Slater River Formation (shale, siltstone) Kusr

lower Cretaceous Sans Sault Formation (sandstone, shale) Klss

Jpper Devonian Imperial Formation (sandstone, siltstone) Dui Dm

Middle Devonian, unnamed and undivided; includes Arnica, Manetoe, Landry, Nahanni, Headless, Funeral, Bear Rock, and Hume Formations (limestone, dolomite, anhydrite, shale)

Middle Devonian Canol Formation (shale) Dmc

Middle Devonian Kee Scarp Formation (reefal and other limestones) Middle Devonian Hare Indian Formation (calcareous shale) Dmhi Dmk

Middle Devonian Bear Rock Formation (dolomite, anhydrite, gypsum) Ordovician-Silurian Mount Kindle Formation (dolomite) Middle Devonian Hume Formation (limestone, shale) Dmb r Dmh 0Sk

Geological contact and fault symbols

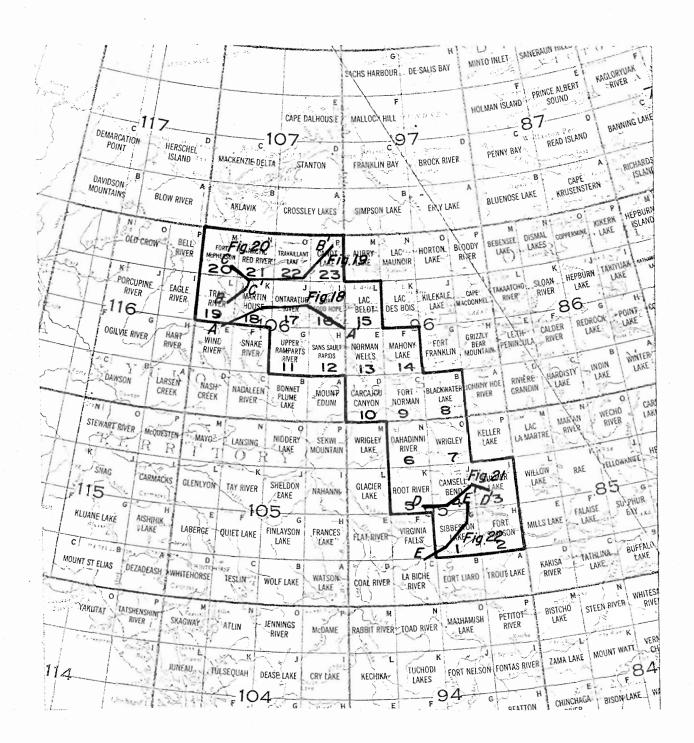
questioned ---?--) Thrust fault (arrows indicate relative movement) Geological formation contact (approximate-

Arrow indicates inferred regional groundwater-flow direction 🖚

Inferred groundwater flow symbol

Horizontal scale: 1 inch = 4 miles as shown Vertical scale:

FIGURE 16



PETROLEUM EXPLORATION DRILLHOLE LOGS SHOWING STATIC WATER LEVEL, TOTAL DISSOLVED SOLIDS AND DIRECTION OF HYDRAULIC GRADIENT IN HOLE

LOCATION OF CROSS-SECTIONS
ALONG

MACKENZIE RIVER VALLEY, N.W.T.
AND
SHOWN IN FIGURES
18, 19, 20, 21, 22

LEGEND FOR FIGURES 18, 19, 20, 21, 22

Cretaceous

K Unnamed and undivided: shale, sandstone

Mississippian

Cm Limestone, phyllite, chert

Upper Devonian

Dui Imperial Formation: sandstone, siltstone, shale

Duhr Hay River Formation: shale, siltstone

Dus Fort Simpson Formation: shale, siltstone

Middle Devonian

Dm Unnamed and undivided; includes Landry, Arnica, and Headless

Formations: limestone, dolomite, shale

Dmh Hume Formation: limestone, dolomite, shale

Dmn Nahanni Formation: limestone, dolomite, shale

Dmk Kee Scarp Formation: reefal and other limestones, dolomite, shale

Dmc Canol Formation: shale, siltstone, limestone

Dmf Funeral Formation: shale, siltstone, limestone

Dmhr Horn River Formation: shale, siltstone, limestone

Dmhi Hare Indian Formation: shale, siltstone, limestone

Dmch Chinchaga Formation: anhydrite, salt, breccia

Ordovician and Silurian

OSk Mount Kindle and Franklin Mountain: dolomite, limestone

Cambrian

6cs Saline River Formation: sandstone, shale, dolomite, gypsum, salt

Precambrian

Precambrian crystalline rocks: gneisses, schists, granitic rocks

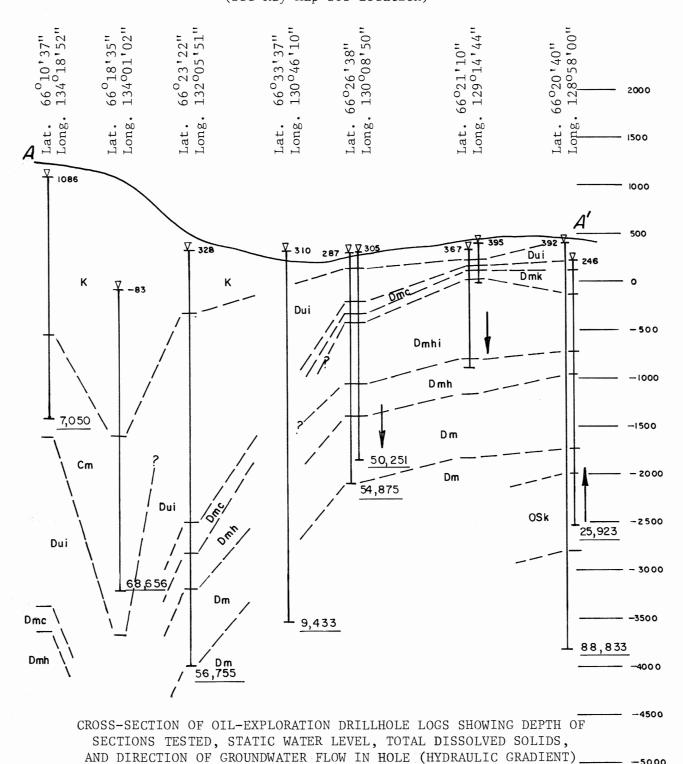
 $\overline{\nabla}$ 382 Elevation of static water level in borehole

138,768 Total dissolved solids content of water in section of borehole tested

1

Direction of hydraulic gradient

STRATIGRAPHIC CROSS-SECTION IN VICINITY OF ARCTIC RED RIVER (see Key Map for location)



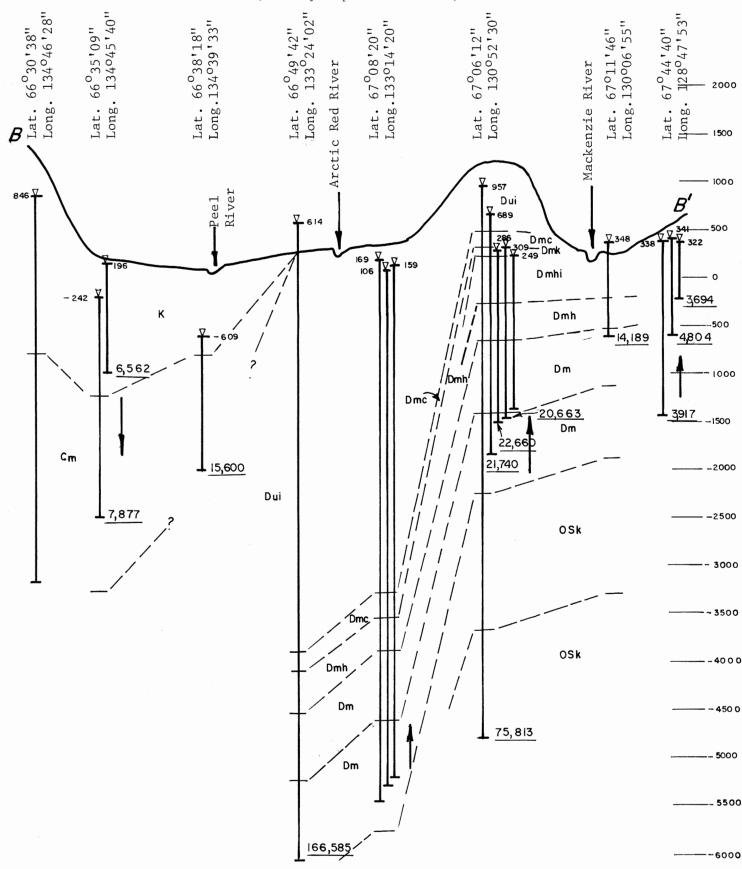
Vertical scale: as shown Horizontal scale: not to scale

J D Mollard and Associates Limited April, 1972

STRATIGRAPHIC

CROSS-SECTION IN VICINITY OF ARCTIC RED RIVER, NORTHWEST TERRITORIES

(see Key Map for location)



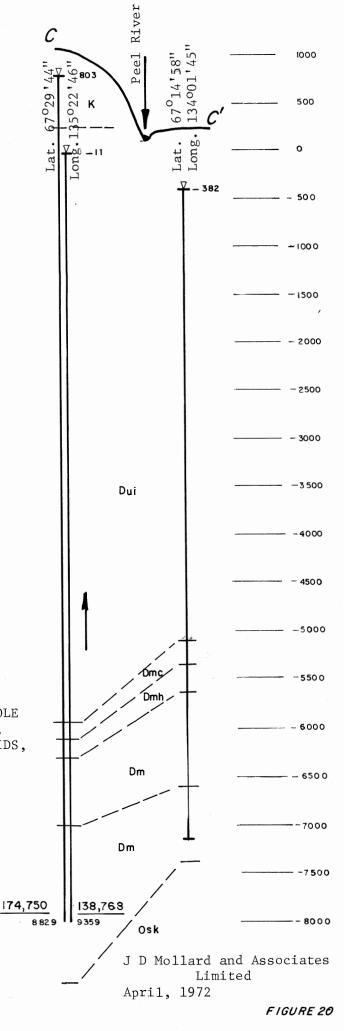
CROSS-SECTION OF OIL-EXPLORATION DRILLHOLE LOGS SHOWING DEPTH OF SECTIONS TESTED, STATIC WATER LEVEL, TOTAL DISSOLVED SOLIDS, AND DIRECTION OF GROUNDWATER FLOW IN HOLE (HYDRAULIC GRADIENT)

Vertical scale: as shown Horizontal scale: not to scale

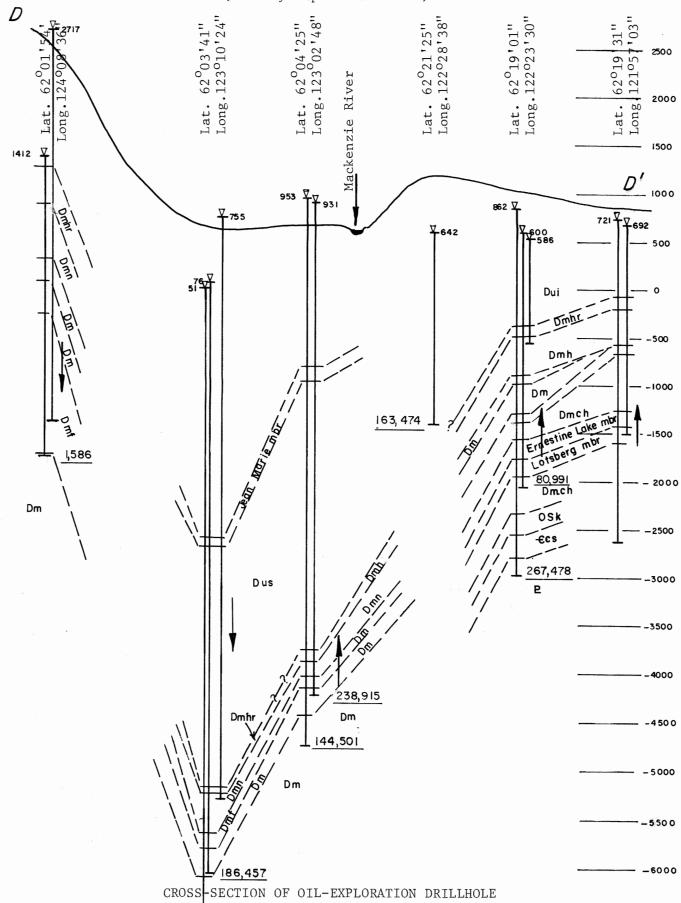
J D Mollard and Associates Limited April, 1972 STRATIGRAPHIC
CROSS-SECTION IN VICINITY
OF ARCTIC RED RIVER,
NORTHWEST TERRITORIES

CROSS-SECTION OF OIL-EXPLORATION DRILLHOLE LOGS SHOWING DEPTH OF SECTIONS TESTED, STATIC WATER LEVEL, TOTAL DISSOLVED SOLIDS, AND DIRECTION OF GROUNDWATER FLOW IN HOLE (HYDRAULIC GRADIENT)

Vertical scale: as shown Horizontal scale: not to scale



STRATIGRAPHIC CROSS-SECTION IN VICINITY OF WRIGLEY, NORTHWEST TERRITORIES (see Key Map for location)



LOGS SHOWING DEPTH OF SECTIONS TESTED, STATIC WATER LEVEL,

AND DIRECTION OF GROUNDWATER FLOW IN HOLE (HYDRAULIC GRADIENT)

Vertical scale: as shown

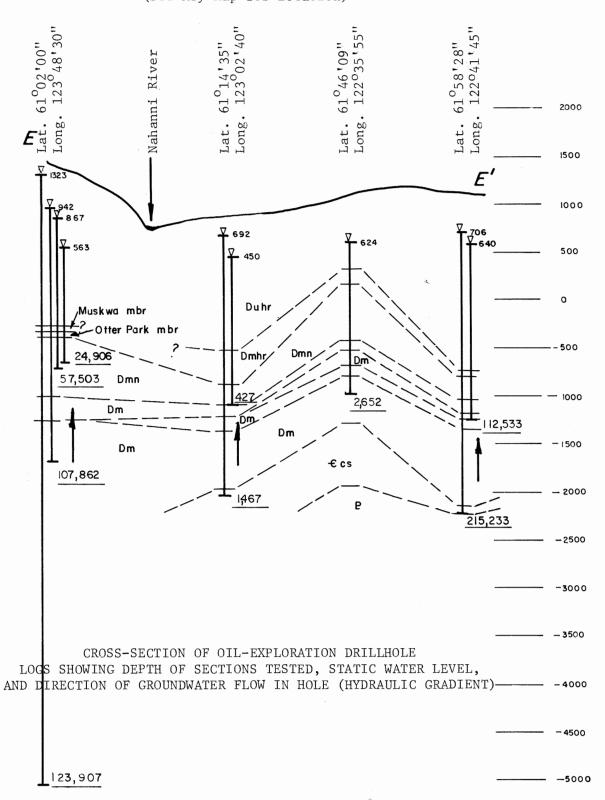
99,767

Horizontal scale: not to scale

April, 1972

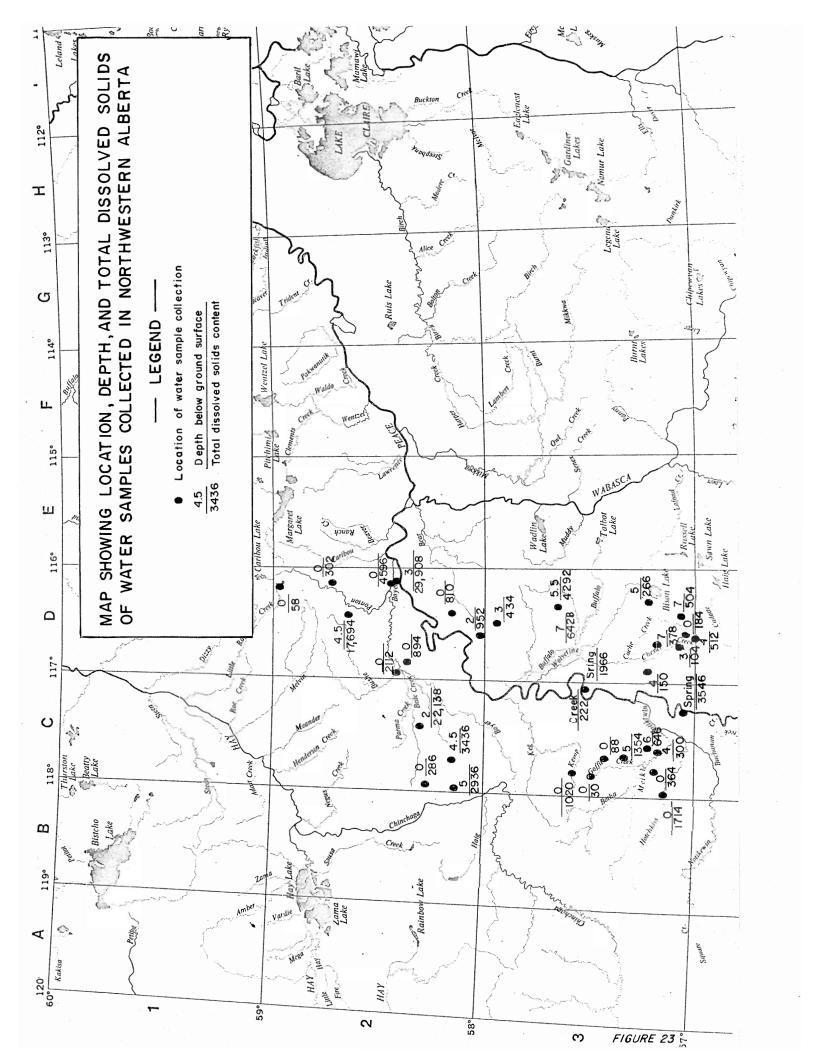
FIGURE 21

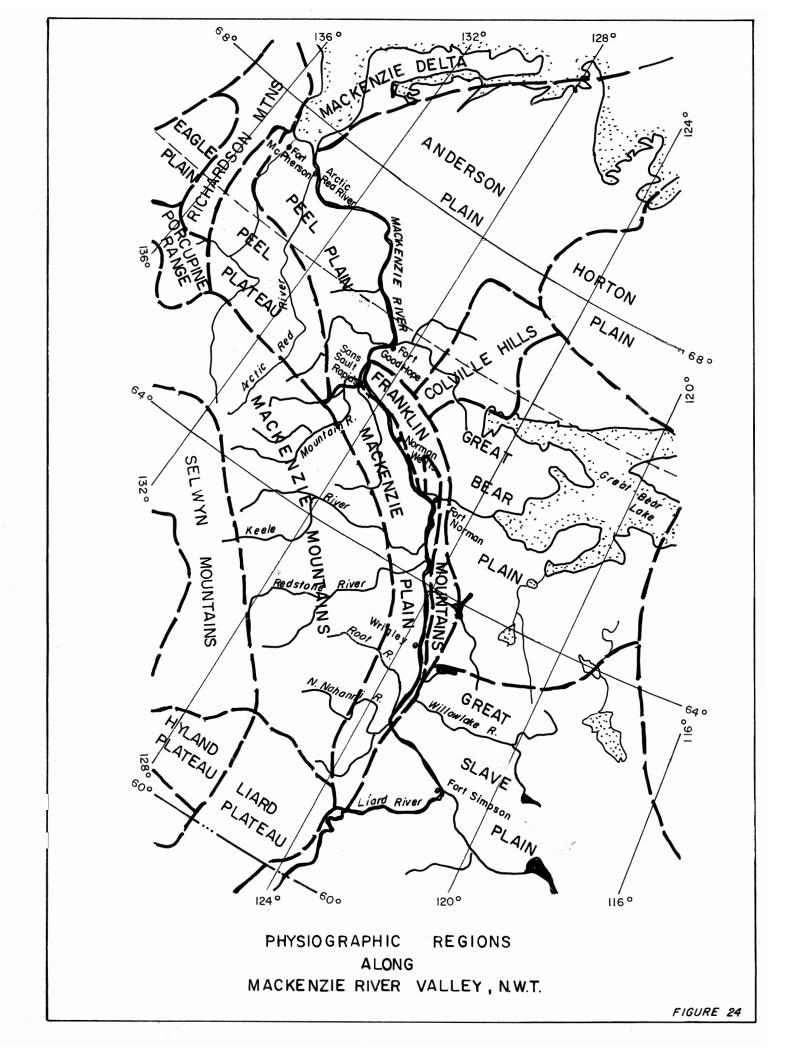
STRATIGRAPHIC CROSS-SECTION VICINITY OF SOUTH NAHANNI -- LIARD RIVERS (see Key Map for location)

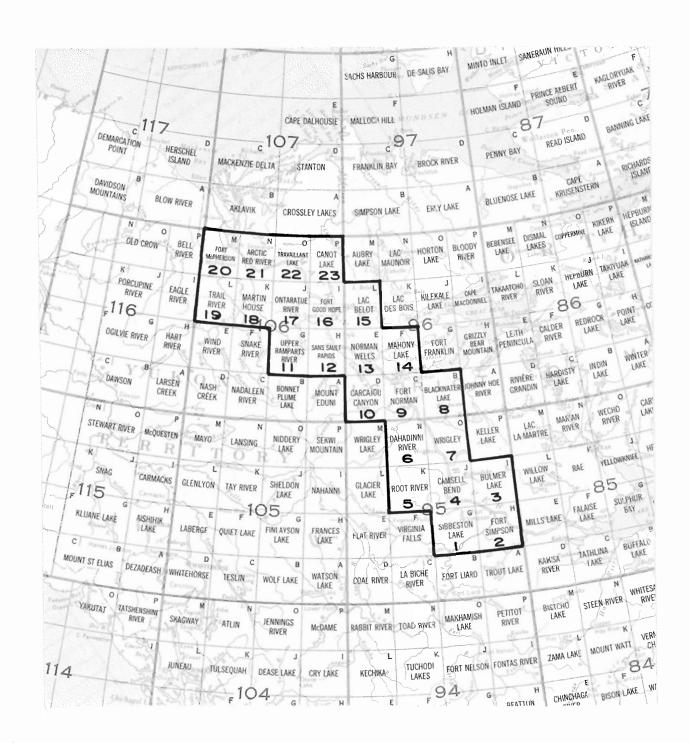


Vertical scale: as shown Horizontal scale: not to scale

J D Mollard and Associates Limited April, 1972

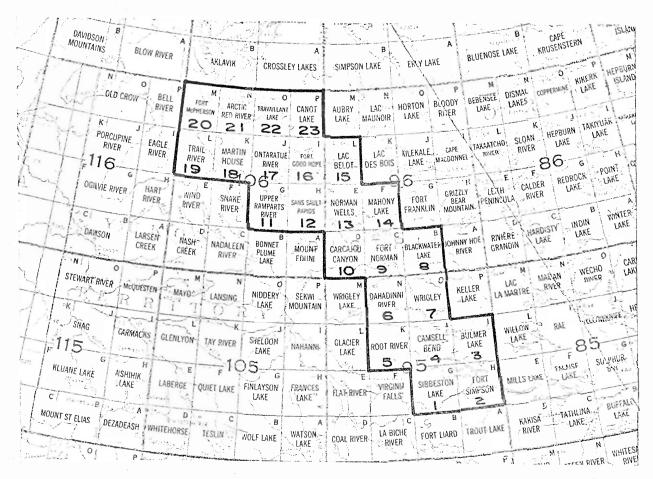






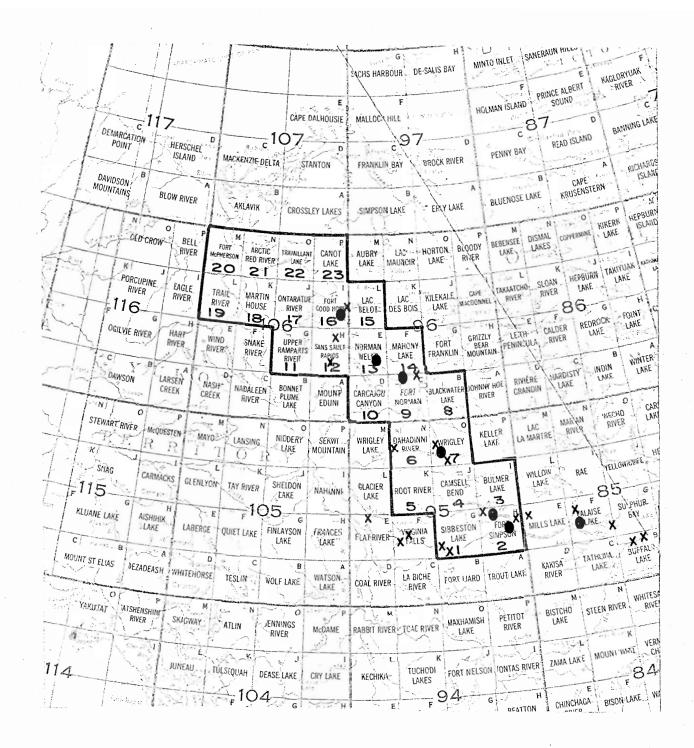
LOCATION OF MAPS ALONG MACKENZIE RIVER VALLEY, NW.T.

ACCOMPANYING 23 SURFICIAL GEOLOGY, 23 SURFICIAL HYDROGEOLOGY, AND 23 BEDROCK HYDROGEOLOGY MAPS AND CORRESPONDING NATIONAL TOPOGRAPHIC MAP SHEET NUMBERS



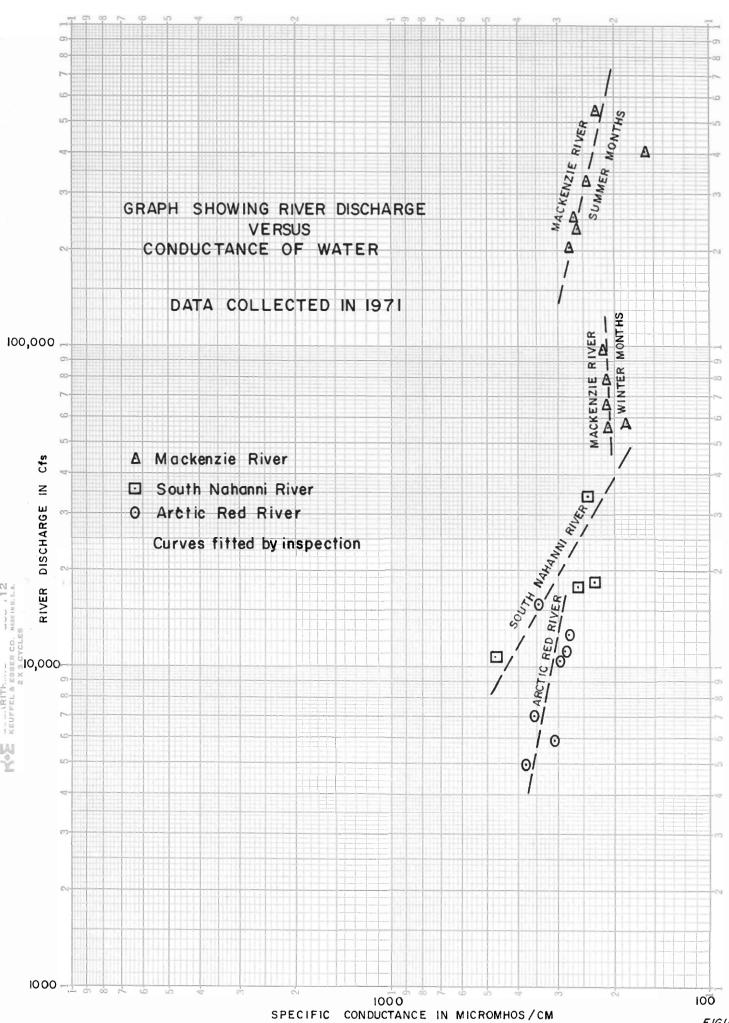
KEY MAP CORRELATING LOCATIONS OF GEOGRAPHIC PLACE NAMES REFERRED TO IN REPORT WITH CORRESPONDING MAP NUMBERS (FIG 25) AND NATIONAL TOPOGRAPHIC SERIES MAP SHEETS (NTS WHERE SHOWN)

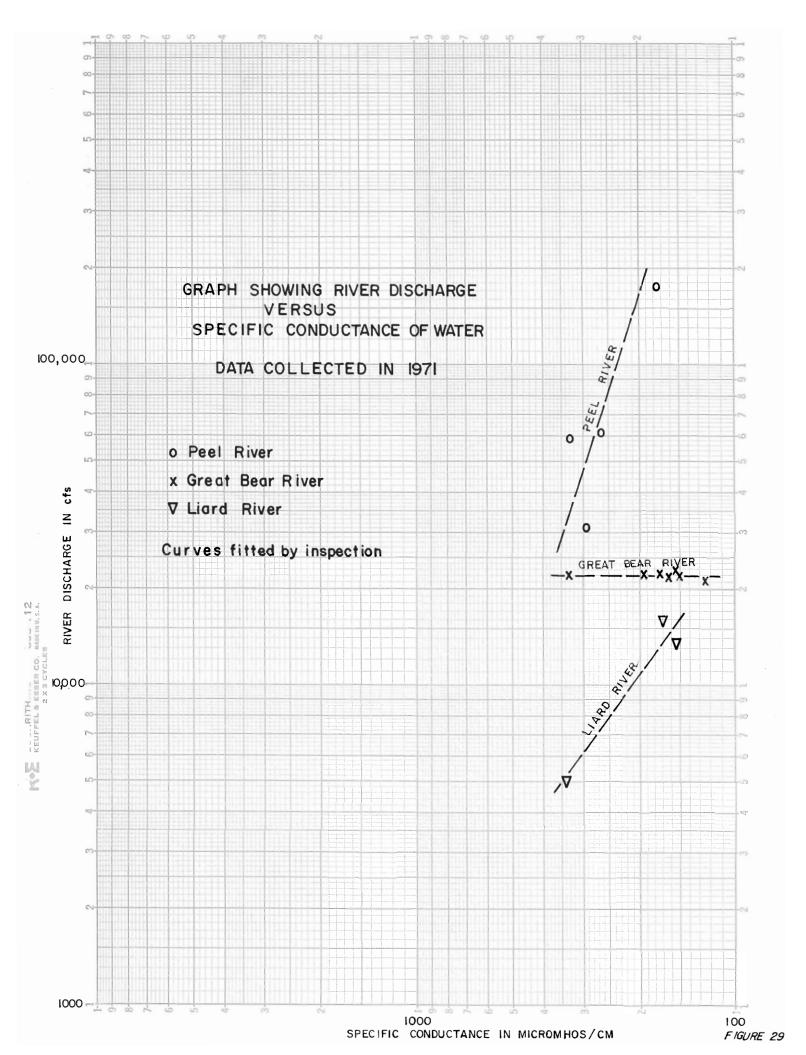
Antoine Lake	2	Lower Donnelly River	12	Slater River 10
Arctic Red River	21	Martin Hills	1	Tathlina
Bear Rock	9	Martin House	18	Lake NTS: 85
Beavertail Point	12	Martin River	1, 2	Trout River NTS:85
Bistcho Lake (Alta)	NTS: 84 M	Mountain River and		and 95
Blackwater River	6	Imperial Hills	12	Vermilion Creek 13
Bogg Creek	13	Mt. Clark	9	West Mountain 12
Bosworth Creek	13	Mount Kindle	7	Wrigley 7
Camsell Bend	4	Mt. Thomas and Mt.Rich	nard 13	
Cap Mountain	7	Mount Morrow	13	
Carcajou River	10	Norman Wells	13	
Dahadinni River	6	North Redstone River	6	
Discovery Ridge	13	North and South Nahanr	ni	
Fort Good Hope	16	Rivers	1,4,5	
Fort Providence	NTS: 85 F	Ochre River	7	
Fort McPherson	20	Old Fort Island	4	
Fort Simpson	2	Old Fort Point	9	
Franklin Mountains	7, 8, 9	Oscar Creek	13	
Goose Island and		Oscar Creek Basin	13	
Bear Island	13	Prohibition Creek	13	
Great Bear River		Rabbitskin River	. 2	•
(rapids section)	14	Redstone River	6 , 9	
Halfway Islands	13	Roche-qui-Trempe-a-		
Hare Indian River	16	1'Eau	7	
Hoosier Ridge	13	Root River	4 , 5	
Kee Scarp	13	Saline River	9	
Keele River	10	Sammon's Creek	12	
Liard River	1, 2	Sans Sault Rapids	12	
Little Chicago	22	Shiltee Rock (Fort		
Lower Carcajou River	10	McPherson)	20	FIGURE 26



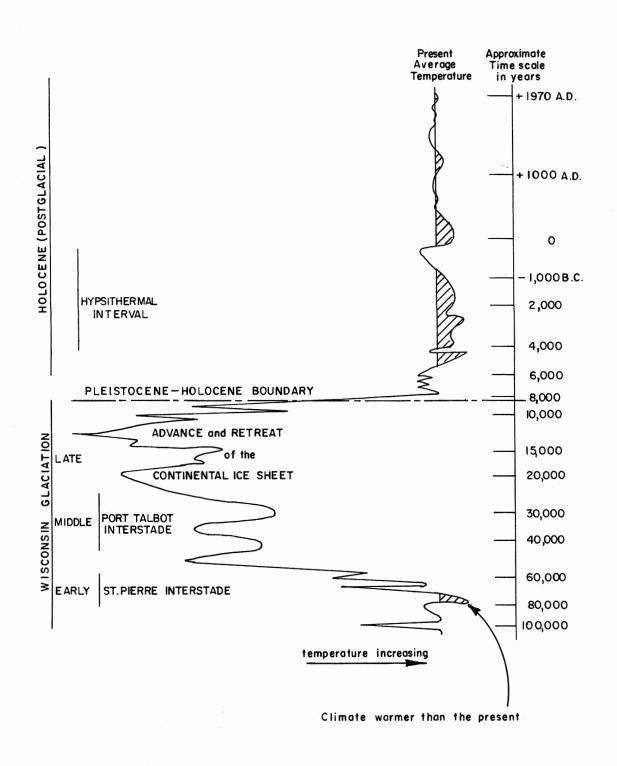
LOCATION OF WATER-WELL DRILLING SITES AND SPRINGS OBSERVED IN FIELD ALONG MACKENZIE RIVER VALLEY, N.W.T.

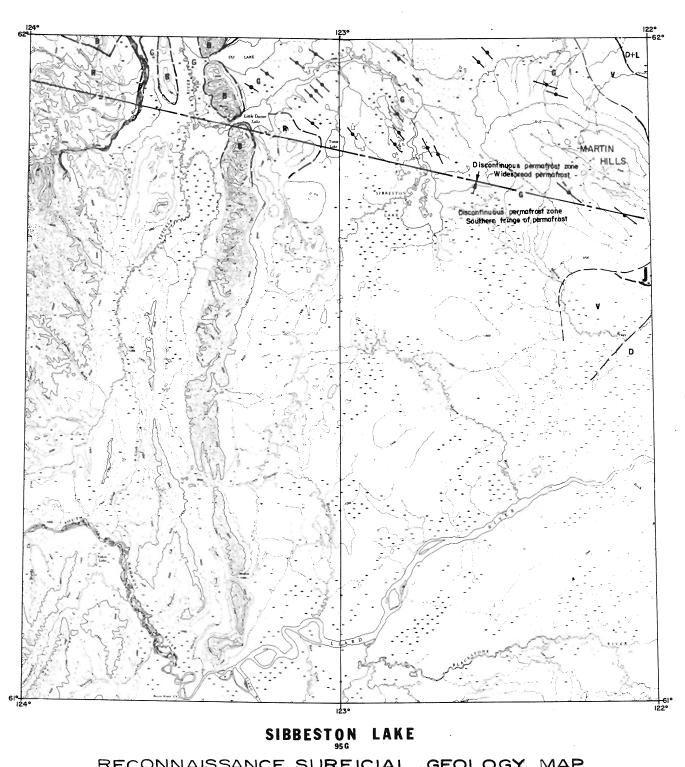
- Water-well drilling sites
- x Springs observed in field





CHANGING CLIMATE DURING WISCONSIN AND POSTGLACIAL TIME (after J. Terasmae, Proceedings 14th Muskeg Research Conference 10 and 11 May 1971, p 158)





RECONNAISSANCE SURFICIAL GEOLOGY MAP



LEGEND OF SURFICIAL DEPOSITS ALONG MACKENZIE RIVER VALLEY FROM FORT SIMPSON TO FORT MC PHERSON, NWT

PLEISTOCENE GLACIAL-DRIFT DEPOSITS NONGLACIAL DEPOSITS

PEATLAND ENVIRONMENT
ORGANIC DEPOSITS: Mainly paat, some
muck; fens, bogs, marshes, and swamps **₩**

FLUVIAL ENVIRONMENT
FLOODPLAIN DEPOSITS: Mointy exposed grows and sond, with thin topertortum of silt and fine s and an the wooded inactive portions of floodpoints; the Mockenzie in the lower reaches of flot-gradient if fibergry rivers consist mainty of stratified silt and fine sand, with minor clay, grows, and stores.

A

ESTUARINE DELTAIC AND FLOODPLAIN DEPOSITS: Moinly complexly intergroding and interfingaring silt, clay, fine sand, and pest with commonly a thick peet cover E ENVIRONMENT

DUNE DEPOSITS: Moinly fine sand, slifty fine sand

D I ACULTATE AND ENVIRONMENT
 D I MANUAL TO A MANUAL TO A

V

clay over 111
GLACIOFLUVIAL ENVIRONMENT
HIGH TERRACE DEPOSITS: Mainly sand
this arrie grows 11 y bads; mostly with a site
and surficial peat cover up to 15 feet thick
locally T 0

IGCOILY
OUTWASH PLAIN, OUTWASH DELTA,
VALLEY TRAIN DEPOSITS - LOCALLY
CHANNELLED AND KETTLED: MOINY
STOTITIES THE DESCRIPTION
STOTITIES THE DESCRIPTION
STOTITIES THE DESCRIPTION
STOTITIES THE DESCRIPTION
ESKERS, CREVASSE FILLINGS, KAMES,
KAME TERRACES, KAME DELTAS
DEPOSITS: Mointy sand and gravel cared

ridges and mounds; with minor sit, 1111, and boulders occurring as inclusions and overglacial environment

H HUMMOCKY MORAINE DEPOSITS (includes a thin cover of fine-grained waterlaid and windled deposit actions to senset in party people of the county of the county

filled deep depressione): Mointy fill
GROUND MORAINE DEPOSITS, GENERALLY
SHOWING STREAMLINED FORMS: (Includes
thin cover of silty to sondy slopewas hopposits
locally): Mointy clay-rich fill over shole strato,
sandy fill over sondstone strato, and silty fill
over combonate rocks; pard deposits on gentle
over combonate rocks; pard deposits on gentle
OFROUND MORAINE DEPOSITS with DEEPER
SLTY TO SANDY SLOPEWISH OVERLAY(Classic
oreas are the slopes of the Ebbut one Mortin Hills
and the Horn Plateau): Mointy silt and sand over fill
BEVELLED TILL DEPOSITS (Include)

BEVELLED TILL DEPOSITS (Include) G

BEVELLED TILL DEPOSITS (Includes pockets of fine waterfold material and peot): Mostly a log concentrate of boulders and cobbies with frequent potches and pockets of sand and grove), waterfold allt and clay, and peot

BEDROCK - DOMINATED TERRAIN

B WIDELY EXPOSED BEDROCK TERRAIN:
Mainly exposed bedrack and bedrack with a
hin, discontinuous vegeer of drift; often
having rugged topography; includes very
rugged ended topography

VENEERED BEDROCK - DOMINATED RELIEF: Moinly a thin, but variable and lacally thick, cover af drift; chiefly till

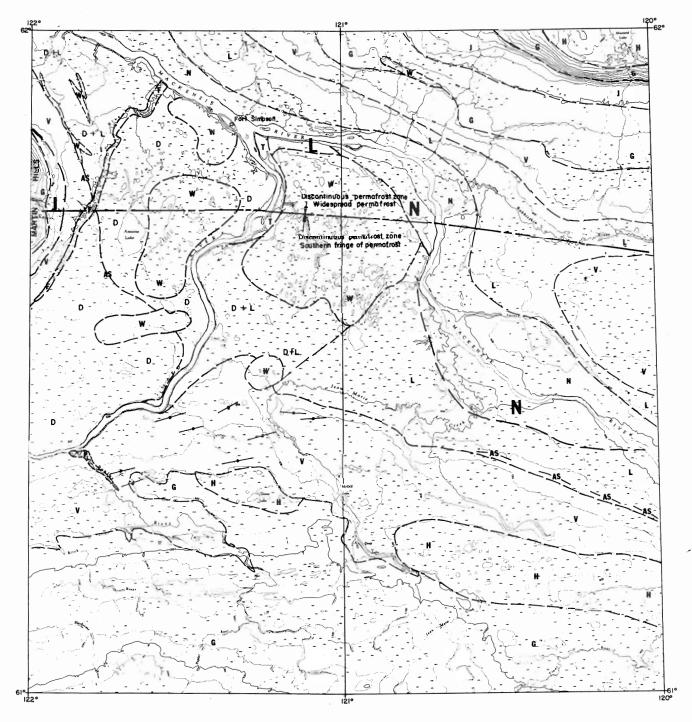
Meltwater and spillway chann Abandoned etrandlines; includes minor rolsed beaches

Karstic topography; sinkhales in solub racks (gypsum, anhydrite, dolomite, limestone)

lce—flow features; includes glacial graoves, glacial fluting, drumlinoid ridges, streamlined hils and ridges, drumlinized landscapes, crag—and-tall hills

Rock gladers, talus, and thick colluvium on steep slopes

Springs



FORT SIMPSON

RECONNAISSANCE SURFICIAL GEOLOGY MAP

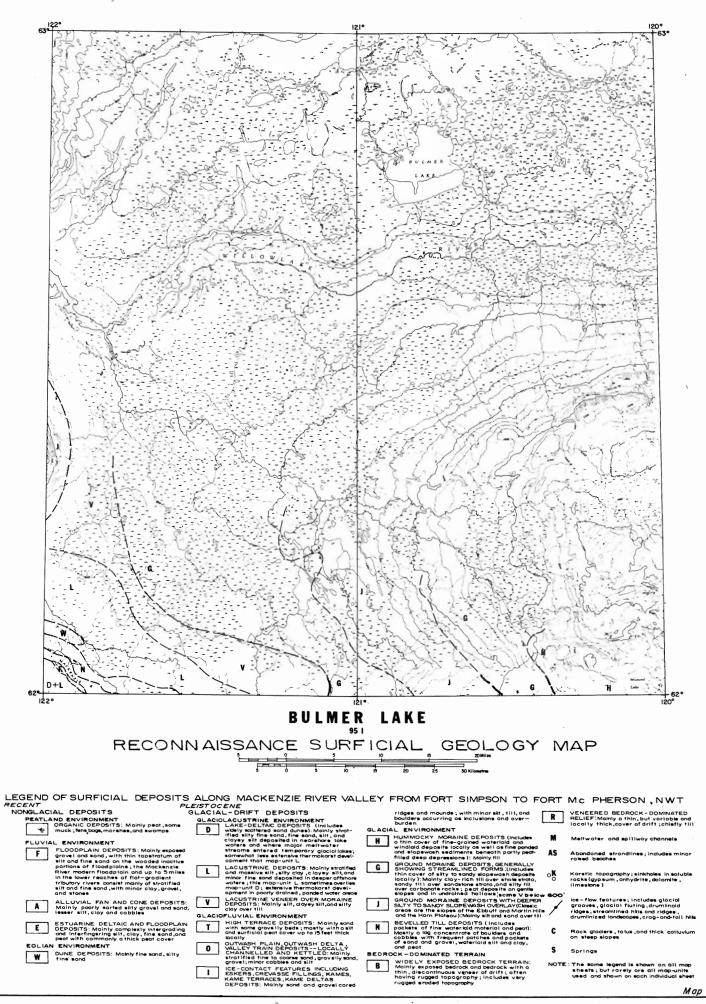


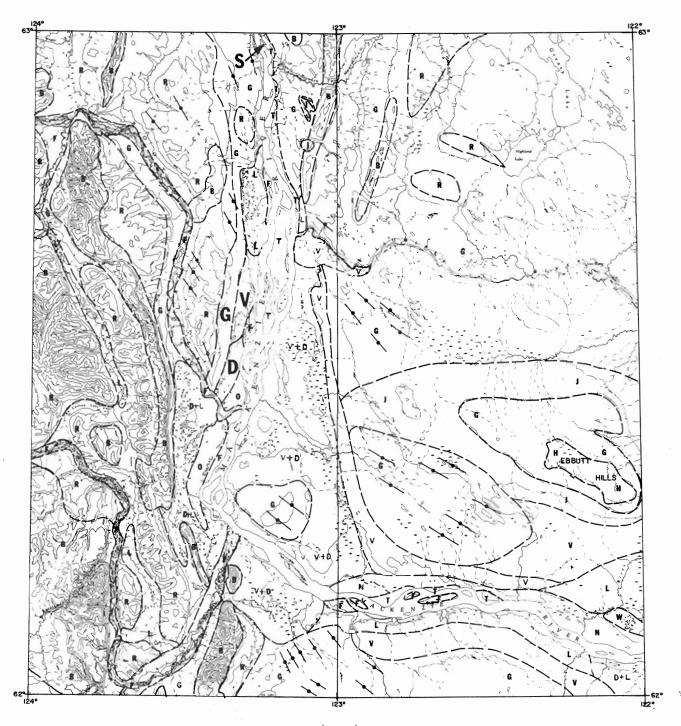
LEGEND OF SURFICIAL DEPOSITS ALONG MACKENZIE RIVER VALLEY FROM FORT SIMPSON TO FORT M.C PHERSON, NWT RECENT NONGLACIAL DEPOSITS PLEISTOCENE GLACIAL-DRIFT DEPOSITS LAUSTRINE DEPOSITS LACUSTRINE SVIRONMENT LAKE-DELTAC DEPOSITS (Includes LAKE-DELTAC DEPOSITS (Includes LAKE-DELTAC DEPOSITS (Includes LAKE-DELTAC DEPOSITS (Includes LAKE-DELTAC DEPOSITS) Includes LAKE-DELTAC DEPOSITS (Includes LACUSTRINE DEPOSITS) LACUSTRINE DEPOSITS (Moinly strottled and measive sill , silly clay, clayer sill, and ord measive sill , silly clay, clayer sill, and orders ; this mop-unit L LACUSTRINE DEPOSITS (Moinly strottled mop-unit D; extensive thermokorat develpment in poorly drained, ponded woter overlies mop-unit D; extensive thermokorat develpment in poorly drained, ponded woter overlie MOP-UNIT D; extensive thermokorat develpment in poorly drained, ponded woter overlie LACUSTRINE VENEER OVER MORAINE LACUSTRINE VENEER OVER MORAINE THIGH TERRACE DEPOSITS: Mainly sond with some grove ity bads; mostly with a sit ord surficiol poet cover up to 15 feet thick OUTWASH PLAIN, OUTWASH DELTA AULEY TRAIN DEPOSITS—LOCALLY R VENEERED BEDROCK - DOMINATED RELIEF: Mainly a thin, but variable and locally thick, cover af drift; chiefly till ridges and mounds; with minor sit; till, and boulders occurring as inclusions and aver— PEATLAND ENVIRONMENT ORGANIC DEPOSITS: Mainly peat, some muck; fens.bogs, marshes, and swamps GLACIAL ENVIRONMENT HUMMOCKY MORAINE DEPOSITS (includes thin cover of fine-grained waterfold and windloid deposits locally as well as fine ponded filled depo deposits and ponded in the cover of sity to sorely slope wesh deposits in the cover of sity to sorely slope wesh deposits in the cover of sity to sorely slope with a position of the cover of sity to sorely slope with an expension of the cover of sity to sorely slope with a cover of sorely slope sorely sorely slope with a cover core to sore and sorely slope with a cover late of the slope slope of the EDET SWITH OF SANDY SLOPE WASH OVERLAY (Classic area or sit the slope of the EDET of the work of the slope slope slope of the EDET of the slope slope of the EDET of the slope slo GLACIAL ENVIRONMENT D Meltwater and spillway channels FLUVIAL ENVIRONMENT

- FLOVIAL ENVIRONMENT

 FOODPLAIN DEPOSITS: Mainly exposed grows I and sand, with thin topstratum of silt and fines and an the wooded inactive partions of floedplain s; the Mackenzle River modern floedplain and up to 5 miles in the lower reaches of flot-gradient tributary rivers consist mainly of stratified silt and fine sand, with minor clay, growsl, and stome L\ A ALLUVIAL FAN AND CONE DEPOSITS:
 Moinly poorly sorted sitty gravel and sond;
 lesser sitt, cloy and cobbles V
- E STUARINE DELTAIC AND FLOODPLAIN DEPOSITS: Mainly complexly intergrading and interfineering sit; cloy, tine sond and peat with commanly a thick peat cover
- EOLIAN ENVIRONMENT W DUNE DEPOSITS: Mainly fine sand, silty fine sand
- iccolly
 OUTWASH PLAIN, OUTWASH DELTA,
 VALLEY TRAIN DEPOSITS -- LOCALLY
 CHANNELLED AND KETTLED: Mighiny
 afroit filed fine to coorse sand, grovely since
 cooking cobbse and since Loung
 ES-COTICCT PATURES
 NOW AMES,
 KAME STEPRACES, KAME DELTAS
 DEPOSITS; Mainly sand ond grovel cored 0

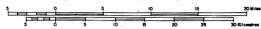
- Karstic tapography; sinkholes in soluble racks(gypsum, anhydrite, dolamite, timestone)
- ridges, streomlined hile and ridges, drumlinized landscapes, crag-and-tail hills
- Rock gladers , tolue , and thick calluvi an steep slapes
- Springs





CAMSELL BEND

RECONNAISSANCE SURFICIAL GEOLOGY MAP



LEGEND OF SURFICIAL DEPOSITS ALONG MACKENZIE RIVER VALLEY FROM FORT SIMPSON TO FORT Mc PHERSON, NWT

RECENT

NONGLACIAL DEPOSITS

ORACIO ACUSTRINE ENVIRONMENT

ORACIO CACUSTRINE ENVIRONMENT

DE LICENTATION CONTROL CACUSTRINE CACUS

FLUVIAL ENVIRONMENT

FLUVIAL ENVIRONMENT

FOODPLAIN DEPOSITS: Moinly exposed gravel and sond, with thin topstratum of all and fine sond on the wooded inactive portions of floodplains; the Mackenzie River modern floodplain and up to 5 miles in the lower reaches of flot-gradlent tributary rivers consist moinly of stratified silt and fine sond, with minor clay, gravel, and stones

ALLUVIAL FAN AND CONE DEPOSITS:
Mainly peorly sorted silty gravel and sand;
lesser silt, clay and cobbies

E STUARINE DELTAIC AND FLOODPLAIN DEPOSITS: Molnly complexly intergrading on interfingering silt, cley, fine sond, one EOLIAN ENVIRONMENT.

EOLIAN ENVIRONMENT.

DUNE DEPOSITS: Molnly fine sond, silty fine sond

LACIAL - DRIFT DEPOSITS
GLACIOLACUSTRINE ENVIRONMENT
LAKE-DELTAK DEPOSITS (Includes
within the property of the sond, silt, and
cloyey silt deposited in near-there lake
waters and where major melt water
streams entered temporary glacial lakes;
separate the sond that the thermokers development the most banks the more recommendation.

opment that mop-unit L
LACUSTRINE DEPOSITS: Mainly stratified
and massive silt; silty clay; claysy silt; and
minor fine sand deposited in desper affshore
waters; this map-unit L sometimes overlies
map-unit D; schesilve thermokarst develapment in poorly drained, ponded water area L

opment in poorty droined, ponded water area

V LOUSTRING VENEER OVER MORAINE
DEPOSITS: Mainly slit, daysy slit, and slity

GLACIOPLUVIAL ENVIRONMENT

HIGH TERRACE DEPOSITS: Mainly send
with some growelty beds ; mostly with a still
and surficial peat cover up to 15 feet thick
locally.

locally

OUTWASH PLAIN, OUTWASH DELTA,
VALLEY TRAIN DEPOSITS -- LOCALLY
CHANNELLED AND KETTLED: Moinly
stroit flied time to coorse sord, grovally sord
grovel; minor cabbles and strick.

ICE-COPTACY PATURES

TO STATE PATURES

KAME TERRACES, KAME DELTAS

DEPOSITS: Moinly samd ond groval cored 0

ridges and mounde; with minor sitt, till, and boulders occurring as inclusions and averburden

RELIEF: Moinly a thin, but variable and boulders occurring the state of the sta

BUTGEN

QLACIAL ENVIRONMENT

HUMMOCKY MORAINE DEPOSITS (includes of this cover of fine-groined waterloid and windled deposities locally as execution of the process of the cover of fine-groined waterloid and windled deposities locally as executions of the process of the cover of

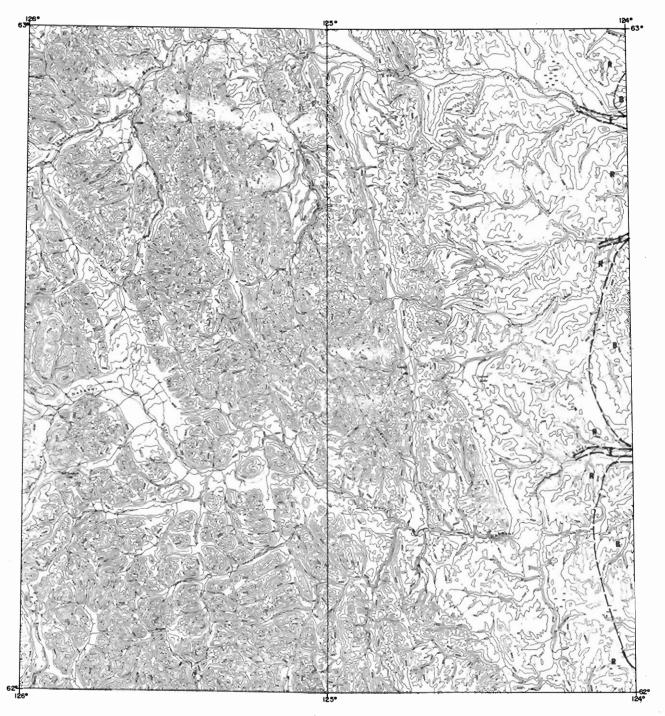
Meltwater and spillway channels

Karetic tapography; sinkholes in solu racks (gypsum , anhydrite , dolomits , timestone)

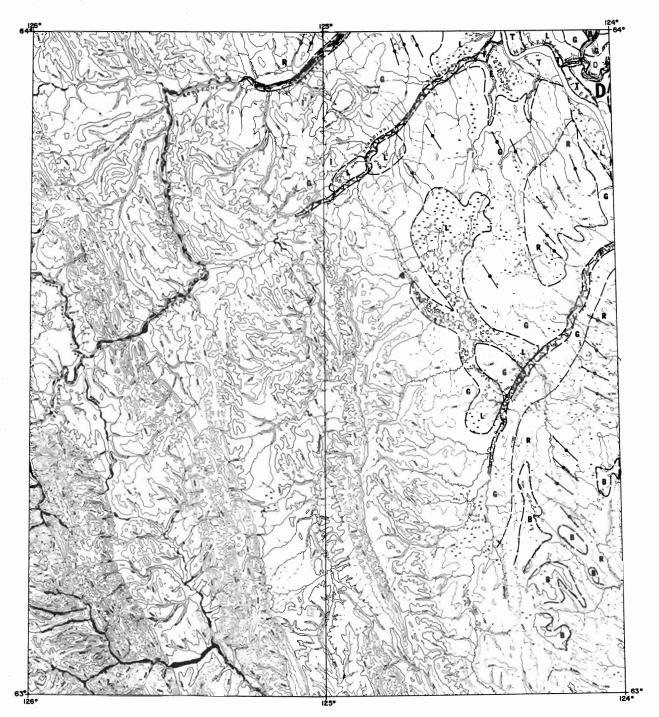
, loe—flow features; includes glacial graoves, glacial fluting, drumlinoid ridges, streomlined hils and ridges, drumlinized landscapes, crag- and-tall hils

Rock gloders , tolus , and thick calluvium on steep slopes

\$ Springs



ROOT RIVER



DAHADINNI RIVER

RECONNAISSANCE SURFICIAL GEOLOGY MAP



LEGEND OF SURFICIAL DEPOSITS ALONG MACKENZIE RIVER VALLEY FROM FORT SIMPSON TO FORT Mc PHERSON, NWT

PLEISTOCENE ' GLACIAL-DRIFT DEPOSITS NONGLACIAL DEPOSITS D I ALCIOLACIONE ENVIRONMENT D I Welst sector and description of the sector and close secto PEATLAND ENVIRONMENT ORGANIC DEPOSITS: Mainly peat, some muck; fens, bogs, marshes, and swampe portions of floodploins; the Modekarile River modern floodploin on dup to 5 miles in the lower reaches of flot-gradient Intributory rivers consist mainly of strottled and stores A LUVIAL FAN AND COME DEPOSITS: Molnly poorly sorted sitty grovel and sond; leaser sitt, cloy and cobbles ESTUARIME DEPOSITS: Molny shortfled opment floot grove sitt, stip (app. 1994) sitt, and minor fine sond deposited in desper offshore minor fine sond deposited in desper of sond minor fi

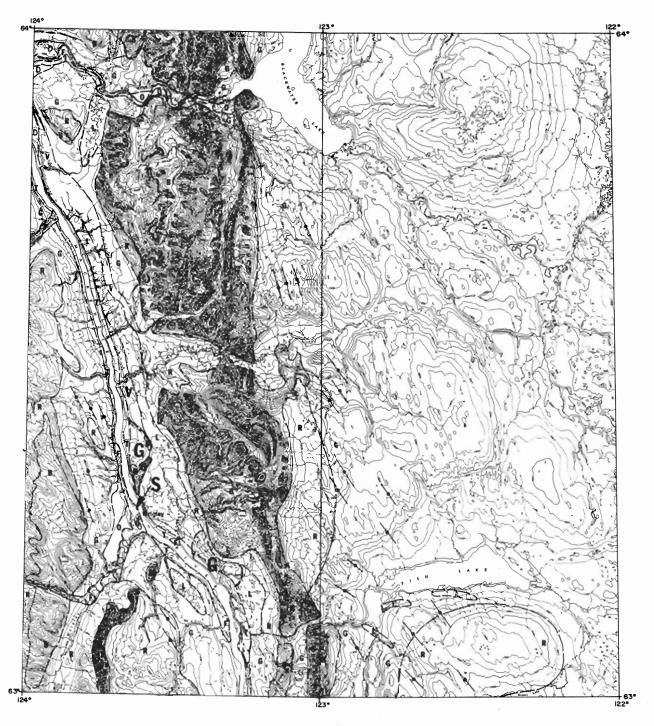
- CLOY OVER THE

 GLACIOPLUVIAL ENVIRONMENT

 HIGH TERRACE DEPOSITS: Mainly sand with some grove ity bads; mostly with as with some grove ity bads; mostly with as with some grove ity to its feet thick backly in the control of the second of the control of the second of the control of the second of the control of the control
- E STUARINE DELTAIC AND FLOODPLAIN DEPOSITS: Mainly complexly intergrading of interfinering all 1, cloy, fine sond, and peat with commonly of thick peat cover EOLIAN ENVIRONMENT
- locally
 OUTWASH PLAIN, OUTWASH DELTA,
 VALLEY TRAIN DEPOSITS -- LOCALLY
 CHANNELLED AND KETTLED: Moinly
 strollied line to coore and, grovelly sind,
 CICE-CONTACT FEATURES INCLUDING
 ESKERS, CREVASSE FILLINGS, KAMES,
 KAME TERRACES, KAME DELTAS
 DEPOSITS: Moinly sond and grovel cored 0 DUNE DEPOSITS: Moinly fine sand, silty fine sand
- ridges and mounds; with minor sit; 111, and boulders accurring as a halustons and overbuilders occurring as a halustons and overbuilders.

 GLACIAL ENVIRONMENT

 HUMMOCKY MORAINE DEPOSITS (includes a hin cover of fine-grained waterfold and windlaid deposits locally as well as fine panded and slopewish as adiments beneath partly peetfilled deep depressions); Mornly till lower shale strick, sandy till over till over shale strick, sandy till over till over shale strick, sandy till over till ove B WIDELY EXPOSED BEDROCK TERRAIN:
 Mointy exposed bedrock and bedrock with a
 hin, discontinuous veneer of drift; often
 hoving rugged topography; includes very
 rugged ended topography



WRIGLEY

RECONNAISSANCE SURFICIAL GEOLOGY MAP

LEGEND OF SURFICIAL DEPOSITS ALONG MACKENZIE RIVER VALLEY FROM FORT SIMPSON TO FORT MC PHERSON, NWT **RECENT** NONGLACIAL DEPOSITS **PEATLAND ENVIRONMENT** ORGANIC DEPOSITS: Moinly ped, some **The muck; first, bogs, morshes, and swamps **FUOVINIONMENT** **FLOODPLAIN DEPOSITS: Moinly exposed gravel and sond, with thin topstratum of gravel and sond, with thin to ridges and mounds; with minor sit; till, and boulders occurring as inclusions and overburden GLACIAL ENVIRONMENT HUMMOCKY MCRAINE DEDESITS (includes with ministed and single state) and single state of rift; chieffy till ministed single state is locally as well as fine pended and slopewish sediments beneath partly peotrifiled deep depressions); Monity till over shorts, and still over shorts, and still state incover of stift to sandy stopes and should be contained by the sandy stopes and should be contained by the sandy stopes and should be stoped and stopes and in undrained the literature of the stope state of the stat

FUNDAMENT COOPLAIN DEPOSITS: Mainly exposed gravel and sand, with thin topstratum of sill and fine sond on the wooded inactive portions of floodpiolins; the Mackenzis River modern floodpiolin and up to 5 miles in the lower reaches of flot-gradient tribulary rivers consist mainly of stratified sill and fine sand, with minor clay, grows, and stones

E STUARINE DELTAIC AND FLOODPLAIN DEPOSITS: Moinly complexly intergrading on interfingering silt, city, fine sond and peat with commanly of thick peat cover

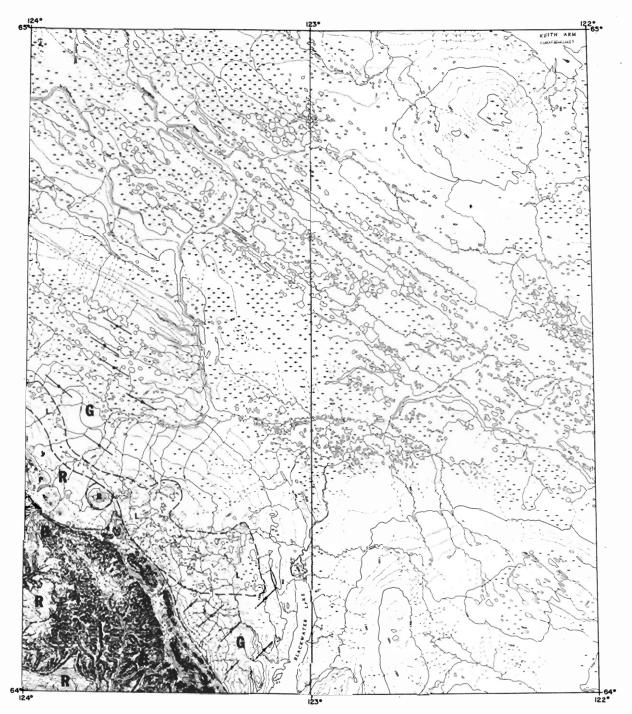
W DUNE DEPOSITS: Moinly fine sand, sitty fine sand

LACUSTRINE DEPOSITS: Mainly stratified and massive silt, silty clay, a layer silt, and minor fine sond deposited in deeper offshore waters; this map-unit L sometimes overlies map-unit 0; extensive thermokarst development in poorly drained, panded water areas.

THE COLUMN TO CO

B WIDELY EXPOSED BEDROCK TERRAIN;
Moinly exposed beforck onbedrock with a
hin, discontinuous veneer of drift; often
having rugged topa graphy; includes very
rugged eroded topagraphy

NOTE; The same legend is shown on all map sheets; but rarely are all map-units used and shown on each individual sheet



BLACK WATER LAKE

RECONNAISSANCE SURFICIAL, GEOLOGY MAP

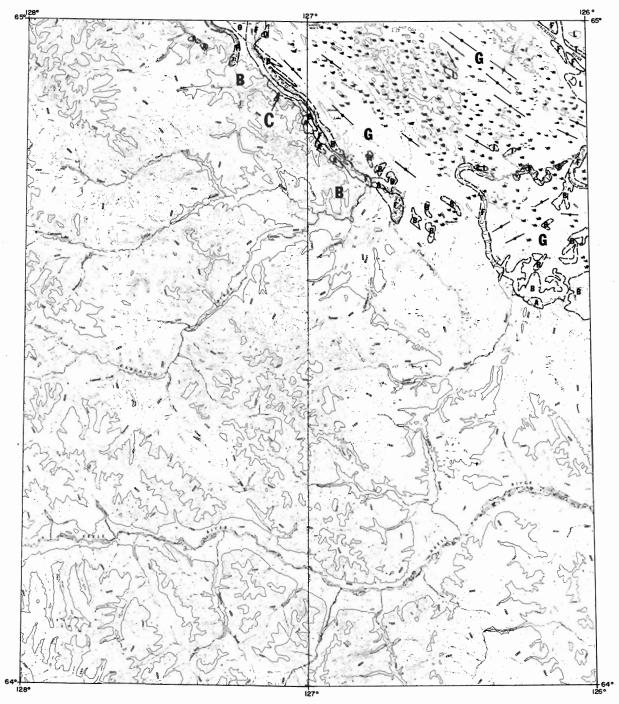
LEGEND OF SURFICIAL DEPOSITS ALONG MACKENZIE RIVER VALLEY FROM FORT SIMPSON TO FORT Mc PHERSON, NWT RECENT NONGLACIAL DEPOSITS ORANIC DEPOSITS ORANIC DEPOSITS: Molinly peet, some muck; timp, book, marehee, and swamps muck; timp, book, marehee, and swamps muck; timp, book, marehee, and swamps Mackenzie Posits ORANIC DEPOSITS: Moliny peet, some muck; timp, book, marehee, and swamps muck; timp, book, marehee, and swamps Mackenzie Posits (includes Deposits ALONG DEPOSITS (includes GLACIAL DEPOSITS GLACIAL DEPOSITS GLACIAL DEPOSITS (includes ORANIC DEPOSITS: Moliny peet, some muck; timp, book, marehee, and swamps muck; timp, book, marehee, and swamps Mattwater and spillway channels ridgee and mounds; with minor sit; till, and bouldare occurring as inclusions and over-burden QLACIAL ENVIRONMENT RELIEF: Mainly a thin, but variable and locally thick, cover of drift; chiefly till Meltwater and spillway channels H FLUVIAL ENVIRONMENT opment in poorty drained, ponded worker over LQUSTRINE VENEER OVER MORAINE DEPOSITS: Molnly slit, daysy slit, and slity closely over till gLACIOPLUVIAL ENVIRONMENT THIS TERRACE DEPOSITS: Molnly sond with some grave it b ice—flow fectures; includes glacial grooves, glacial fluting, drumlinoid ridges, streomlined hills and ridges, drumlinized landscapes, crag-and-tall hills BEDROCK - DOMINATED TERRAIN B WIDELY EXPOSED BEDROCK TERRAIN Mointy exposed bedrock and bedrock with a hin, discontinuous veneer of drift; often having rugged topography; includes very rugged ended topography.



FORT NORMAN

RECONNAISSANCE SURFICIAL GEOLOGY MAP

EGEND OF SURFICIAL DEPOSITS PLESTOCENE ONOBLACIAL DEPOSITS ONDELACIAL DEPOSITS ONDELACIAL



CARCAJO U CANYON

RECONNAISSANCE SURFICIAL GEOLOGY MAP



LEGEND OF SURFICIAL DEPOSITS ALONG MACKENZIE RIVER VALLEY FROM FORT SIMPSON TO FORT Mc PHERSON, NWT
RECENT
NONGLACIAL DEPOSITS

DEPOSITS ALONG MACKENZIE RIVER VALLEY FROM FORT SIMPSON TO FORT Mc PHERSON, NWT
PLEISTOCENE
GLACIAL DEPOSITS

DEPOSITS ALONG MACKENZIE RIVER VALLEY FROM FORT SIMPSON TO FORT MC PHERSON, NWT
RECENT.

DEPOSITS ALONG MACKENZIE RIVER VALLEY FROM FORT SIMPSON TO FORT MC PHERSON, NWT
RECENT.

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RECENT.

DEPOSITS ALONG MACKENZIE RIVER VALLEY FROM FORT SIMPSON TO FORT MC PHERSON, NWT
RECENT.

DEPOSITS ALONG MACKENZIE RIVER VALLEY FROM FORT SIMPSON TO FORT MC PHERSON ridges and mounde; with minor skit, till, and bouldere occurring as inclusions and over-burden.

R VENEERED BEDROCK - DOMINATED RELIEF! Moinly a thin, but variable and burden oldcolly thick, cover of drift; chiefly till GLACIAL ENVIRONMENT Н F G

over corbonals rocks, a set deposits on gents

GROUND MORAINE DEPOSITS WITH DEEM
SILTY TO SANDY SLOPEWASH OVERLAY(Close)

SILTY TO SANDY SLOPEWASH OVERLAY(Close)

N BEVELLED TILL DEPOSITS (Includes pockets of fine waterbid material and paor):
cobbies with frequent potches and pockets of sond and gravel, waterbid and cloy, and paor)

BEDROCK - DOMINATED TERRAIN

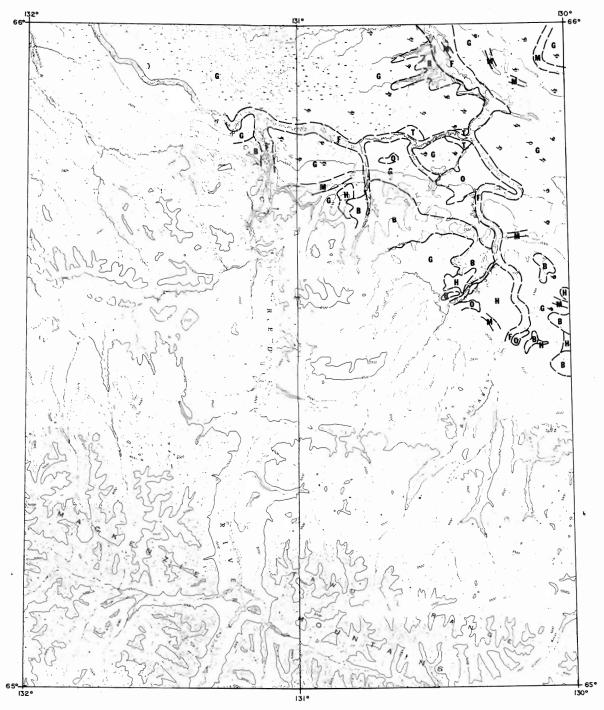
Mainly sepased bedrock and bedrack with a holding supposed bedrack and bedrack with a holding rugged at papagraphy; includes very rugged a roded topography; includes very Opment in poorty drained, ponded water area

LOUSTRING VENEER OVER MORAINE
Clay Over 11 Monthly silt, doyey silt, and silty
clay over 11 Monthly silt, doyey silt, and silty
clay over 11 Monthly silt, and silty
clay over 11 Monthly silty over 11 Monthly sond

T with some grove tilty bads ; mostly with a silt
and surficial peot cover up to 15 feet thick
locally sill and in Monthly Del TA E STUARINE DELTAIC AND FLOODPLAIN DEPOSITS: Mainly complexly intergrading and interfingering silt, clay, fine sond, and ped with commonly a thick peat caver

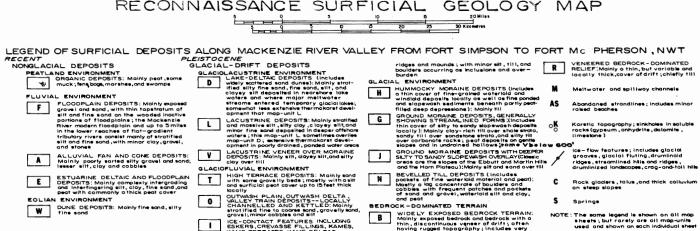
iocolly
OUTWASH PLAIN, OUTWASH DELTA,
VALLEY TRAIN DEPOSITS -- LOCALLY
CHANNELLED AND KETTLED: Moinly
strotified time to coorse sand, grovely sond
grovel; minor cobbse and sill including
IEE-CONTACT FEATURES INCLUDING
EXERS, DEEVASSE FILL MOS, KAMES,
KAME TERRACES, KAME DELTAS
DEPOSITS: Moinly sand and grovel cared

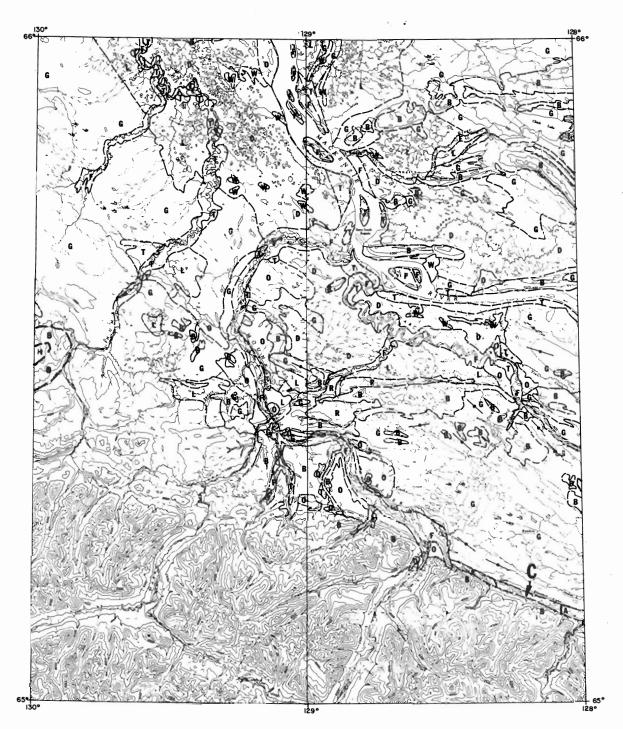
ice—flow features; includes glacial graces, glacial fluting, drumlinald ridges, streamlined hits and ridges, drumlinized landscapes, crag—and-tall hits Rack gladers, talus, and thick calluvium on steep slapes



UPPER RAMPARTS RIVER

RECONNAISSANCE SURFICIAL GEOLOGY MAP





SANS SAULT RAPIDS

RECONNAISSANCE SURFICIAL GEOLOGY MAP

LEGEND OF SURFICIAL DEPOSITS ALONG MACKENZIE RIVER VALLEY FROM FORT SIMPSON TO FORT MC PHERSON, NWT

PECENT
NONGLACIAL DEPOSITS
OLACIAL-DEPOSITS
OLACIAL-DEPOSITS (Includes burden on dover-burden of third cover of principles or incontrol third still river, burden on deposit of the cover of third cover of ridges and mounde; with minor skt, till, and bouldere occurring as inclusions and over-burden. RELIEF: Mainly a thin, but variable and locally thick, cover of drift; schiefly till

E STUARINE DELTAIC AND FLOODPLAIN DEPOSITS: Moinly complexly intergrading on different partial company of the sond and pool with command or thick peak cover.

W DUNE DEPOSITS: Moinly fine sand, silty fine sand

opment that map-unit L

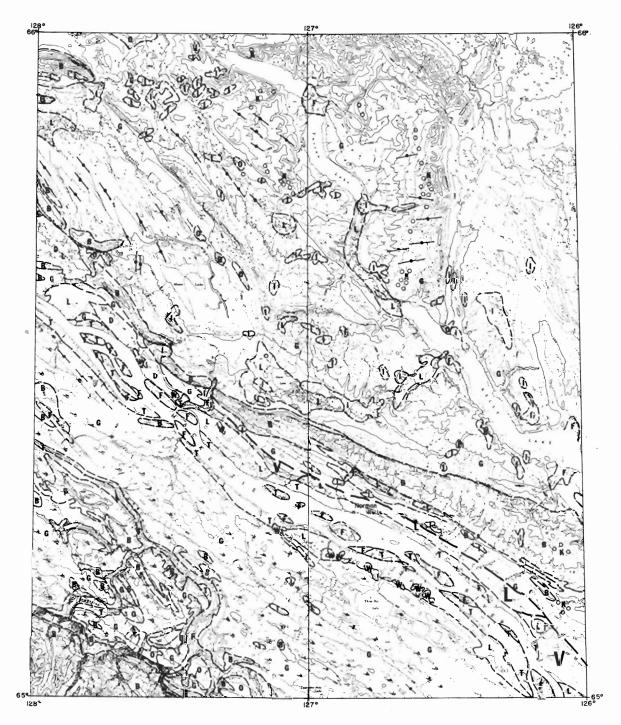
LACUSTRINE DEPOSITS: Mainly stratified
and massive silt, elity clay , claysy silt, and
minor fine sand deposited in desper offshore
waters; this map-unit L sametimes overlies
map-unit D; extensive thermokorat develapment in poorly drolled, panded water areas

V LACUSTRINE VENEER OVER MORAINE DEPOSITS: Mointy silt, doyey silt, and eity clay over till

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GREVIANT STATES OF THE STATES

S - Springs



NORMAN WELLS

RECONNAISSANCE SURFICIAL GEOLOGY MAP



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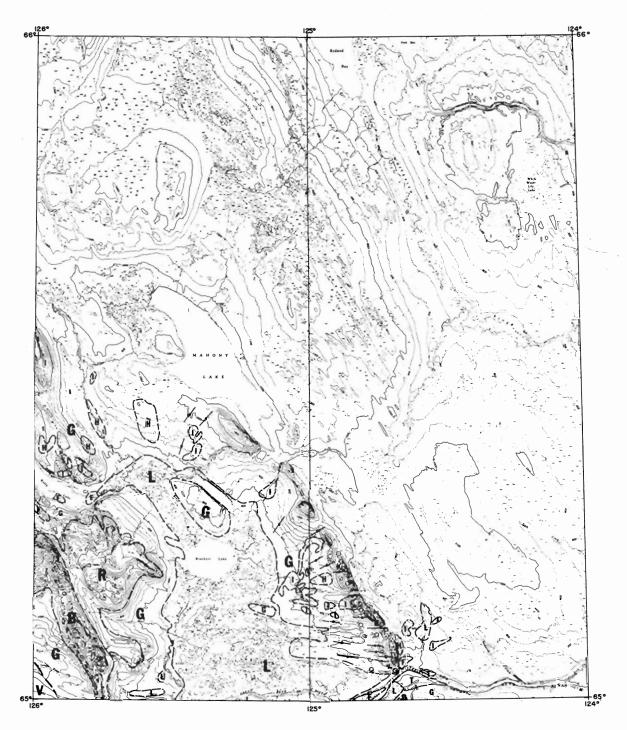
locally
OUTWASH PLAIN, OUTWASH DELTA,
VALLEY TRAIN DEPOSITS - LOCALLY
CHANNELLED AND KETTLED: Moining,
strail filed fine to coorse sand, grovelly son,
CE-CONTACT FEATURES INCLUDING
ESKERS, CREVASSE FILLINGS, KAMES,
KAME TERRACES, KAME DELTAS
DEPOSITS: Mainly sand and graval cored

G

over corbonate rocks; peot deposits on detries and control of the control of the

ice—flow factures; includes glocial grooves, glocial fluting, drumlinold ridges, streamlined hills and ridges, drumlinized landscapes, crag—and-tall hills

Rock gloders , talus , and thick colluvium on steep slapes



MAHONY LAKE

RECONNAISSANCE SURFICIAL GEOLOGY MAP



- ESTUARINE DELTAIC AND FLOODPLAIN DEPOSITS: Moinly complexly intergrading and interfingering silt, clay, fine sand, and past with commanly a thick peet cover ENVIRONMENT

- ocolly

 OUTWASH PLAIN, OUTWASH DELTA,
 VALLEY TRAIN DEPOSITS -- LOCALLY
 CHANNELLED AND KETTLED: Moinly
 strotified line to coorse and, growily sord,
 grovel; minor cobbise and sill
 IEECOSTACT FEATURES MOLLUDING
 EXCESTACT FEATURES MOSI, KAMES,
 KAME TERRACES, KAME DELTAS
 DEPOSITS: Moinly sord and gravel cored
- GLACIAL ENVIRONMENT

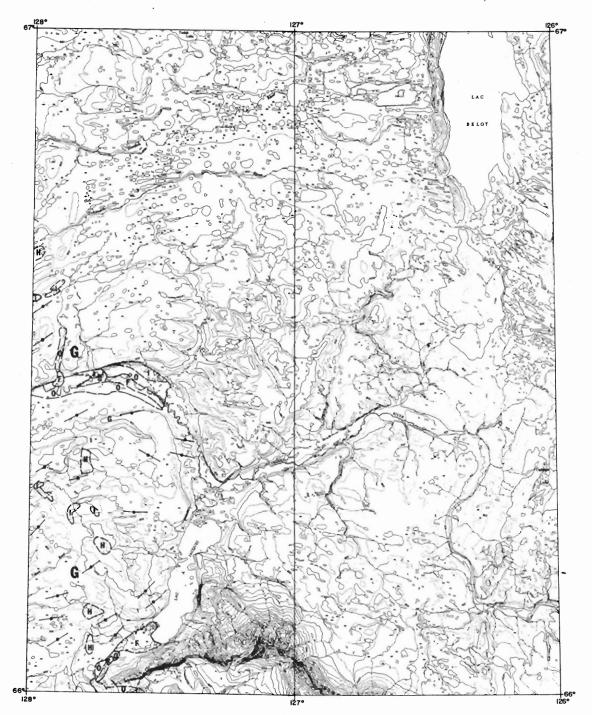
 H WIMMOCKY MORAINE DEPOSITS (includes thin cover of tine-groined waterfold and windled deposits locally as well as fine ponded and slapewash sediments beneath partly perfilled deep depressione): Moliny till

 GROUND MORAINE DEPOSITS, GENERALLY

 WIMMOSTREAMLINED FORMS (includes the properties of th

WIDELY EXPOSED BEDROCK TERRAIN Mainly exposed bedrock and bedrock with a thin, discontinuous veneer of drift; often having rugged topography; includes very rugged eroded topography

- ice—flow features; includes glacial graces, glacial fluting drumlinoid ridges, streamlined hills and ridges, drumlinized landscopes, crag-and-tail hills
 - Rack gladers , talus , and thick calluvium an steep slapes
 - Springs



LAC BELOT

RECONNAISSANCE SURFICIAL GEOLOGY MAP



FLUVIAL ENVIRONMENT AL ENVIRONMENT
FLOODPLAIN DEPOSITS: Moinly exposed
grove! ond sond, with thin topstratum of
sitt ond fine sand on the wooded inactive
portions of floodpioline; the Mockenzie
River modern floodpiolin and up to 3 miles
in the lower reaches of flot-gradient
ributary rivers consist modify of strottled
sitt ond fine sond, with minor cloy, growel,
ond stones portions of flood ploine; the Mockenzie River modern flood ploine; the Mockenzie River modern flood ploin on dup to 5 miles in the lower reaches of floot-gradient tributory rivers consist monity of stratified silt and fine sond, with minor clay, grovel, and stones

A ALLUVIAL FAN AND CONE DEPOSITS:

A MINING porty sorted silty gravel and sond; lesser stilt, clay and cobbles

A CLUVIAL FAN AND CONE DEPOSITS: Moliny silt, dayey silt, and silty gravel and sond; lesser stilt, clay and cobbles

A GLAUSTRINE DEPOSITS: Moliny benefit and minor fine sond deposited in desper offshore waters; this mop-unit L some point from point in mop-unit L some point from point in mop-unit L some point from point in many silt, silt and point silt, silt and point silt, silt and point silt and possible silt, silt and point silt, silt and point silt and point

E ESTUARINE DELTAIC AND FLOODPLAIN DEPOSITS: Moinly complexly intergrading and interfrageling silt, clay, this sand, and EOLIAN ENVIRONMENT

W DUNE DEPOSITS: Moinly fine sand, silty fine sand

D id.Aciol.Acustrine Environment

D id.Aciol.Acustrine Environment

D id.Aciol.Acustrine Environment

but a condition of the condition of the

BOUIGERS OCCURING OB RECIDENCE OF THE CONTROL OF TH

stopes and in undrained hallows (3 of me Y bell of GOUND MORAINE DEPOSITS WITH DEEPER SLTY TO SANDY SLOPEWASH OVERLAY(Closeld cross are the slopes of the Ebbutt and Morth Hills and the Harn Plateau); Walniny silt and sand over till be specified to the Harn Plateau; Walniny silt and sand over till pockets of time waterfold material and peat); Mostly a log concentrate of boulders and on the day of sand and gravel, waterfold silt and clay, and peat.

BEDROCK - DOMINATED TERRAIN

B WIDELY EXPOSED BEDROCK TERRAIN: Molnily exposed beforck and bedrack with a thin, discontinuous vaneer of affit; often having rugged topagraphy; includes very rugged enaded topagraphy.

Meltwater and spillway channels

Abondoned strandlines; includes minor raised beaches

Korstic tapagraphy; sinkholes in soluble rocks (gypsum , anhydrite , dolomite , limestone)

ico *

/ ico - flow fectures; includes glocial

/ ico - flow fectures; includes glocial

grooves, glocial flutting, drumlinoid

ridges, streomlined hits and ridges,

drumlinized landscapes, crag-and-toil hils

Rock glodere, tolus, and thick colluvium on steep slopes

Springs

OTE: The same legend le ehown on all map sheets; but rarely are all map-units used and shawn on each individual shee



FORT GOOD HOPE

RECONNAISSANCE SURFICIAL GEOLOGY MAP



- E STUARINE DELTAIC AND FLOODPLAIN DEPOSITS: Mainly complexly intergrading and interfingering allic, log, fine sond and peat with commanly a thick peat cover
- EOLIAN ENVIRONMENT W DUNE DEPOSITS: Mainly fine sand, silty fine sand
- OPPORT IN poorly droined, panded wother carea ACUSTRINE VENEER OVER MORAINE DEPOSITS: Moinly sitt, doyey sitt, and sitty cloy over till CALCIPELINE ENVIRONMENT

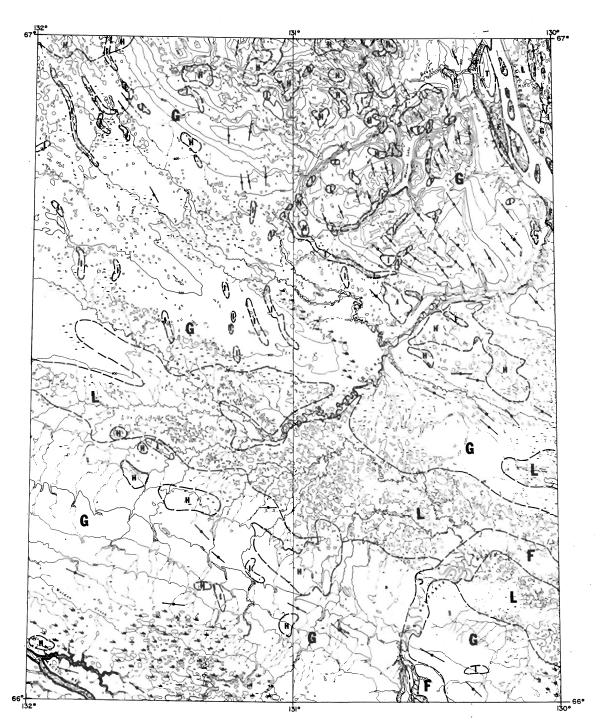
 I HIGH TERRACE DEPOSITS: Moinly sond with some grove ity bade; mostly with osh tocally course up to the thick socially course and grovelly sond, grove
- ond the Horn Ploteou i Worln's sit and sond over

 BUSINESS AND STATES AND STA

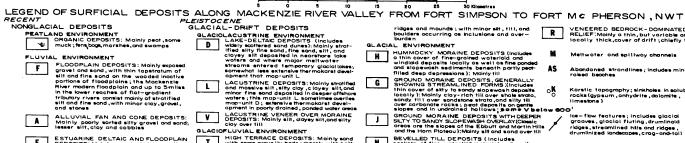
GROUND MORAINE DEPOSITS WITH DEEP
SILTY TO SANDY SLOPEWASH OVERLAY (Class
areas are the slopes of the bibutt and Martin
and the Horn Plateau); Mainty sit and sand over

- Karstic topography; sinkholes in solu rocks (gypsum, onhydrite, dolomite, timestone)

- Rock gladers , talus , and thick calluvium on steep slapes



ONTARATUE RIVER RECONNAISSANCE SURFICIAL GEOLOGY MAP



L ENVIRONMENT
FLOODPLAIN DEPOSITS: Moinly exposed
grovel and sand, with this topatratum of
grovel and sand, with this topatratum
of flood plot in the Mockentie
partions of flood plotins; the Mockentie
Rher modern flood plot and up to 5 miles
in the lower reaches of flot-gradient
rejbutray rivers consist monity of straitfied
silt and fine sand, with minor cloy, grovel,
and stores F

A ALLUVIAL FAN AND CONE DEPOSITS:
Mointy poorly sorted sitty grovel and sond;
leaser sitt, cloy and coobies

GLACIC

E ESTUARINE DELTAIC AND FLOODPLAIN DEPOSITS: Mointy complexity intergrading and interfingering sits, clay, fine eand, and peot with commonly a thick peat cover EOLIAN ENVIRONMENT

W DUNE DEPOSITS: Mointy fine sand, sitty fine sand

GLACIOLA CUSTRING ENVIRONMENT

GLACIOLA CUSTRING ENVIRONMENT

D MAKE-DELTAS DEPOSITS

Moliny softward sand dunes). Molinly sit

clovey sill deposited in nearshors to

stream entered temporary glocial is

somewhat less extensive thermokarst di

opment that mop unit L.

GLACIOFLUVIAL ENVIRONMENT

HIGH TERRACE DEPOSITS: Moinly sond with some grows ity beds; mostly with a silt ond surficial ped cover up to 15 feet thick T

locally
OUTWASH PLAIN, OUTWASH DELTA,
VALLEY TRAIN DEPOSITS -- LOCALLY
CHANNELLED AND KETTLED: Mainly
strailfied fine to coarse sand, gravelly sand,
gravel; minor cobbies and silt 0 grovel; minor cobbles and silf iCE-CONTACT FEATURES INCLUDING ESKERS, CREVASSE FILLINGS, KAMES, KAME TERRACES, KAME DELTAS DEPOSITS: Mainly sand and gravel cared

BEDROCK - DOMINATED TERRAIN

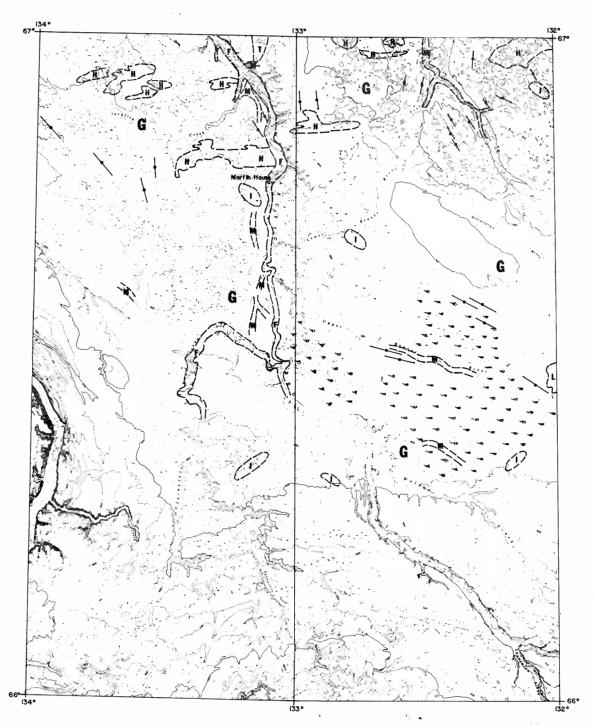
WIDELY EXPOSED BEDROCK TERRAIN; Mointy exposed bedrock and bedrock with a thin, discontinuous veneer of drift; aften having rugged topography; includes very rugged eroded topography

VENEERED BEDROCK - DOMINATED RELIEF: Moinly o thin, but vorioble and locally thick, cover of drift; chiefly till

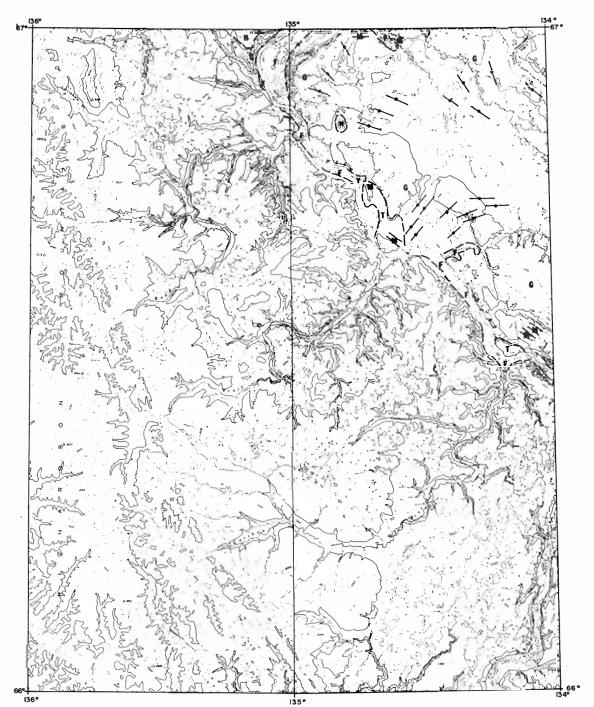
Korstic tapography; sinkholes in solu rocks (gypsum , onhydrite , dolomite , limestone)

)¹ lice-flow features; includes glacial grooves, glacial fluting, drumlinoid ridges, streamlined hits and ridges, drumlinized landscapes, crag-and-tall hits Rock gladers, tolus, and thick colluvium on steep slapes

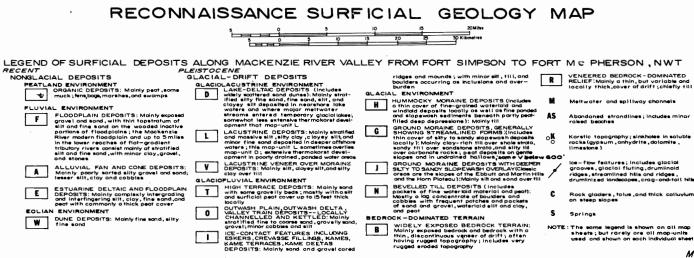
Springs

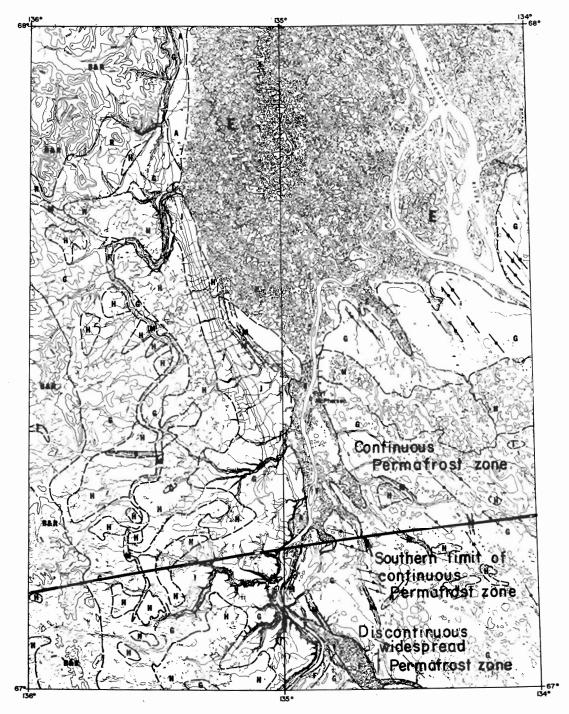


MARTIN HOUSE	
RECONNAISSANCE SURI	FICIAL, GEOLOGY MAP
LEGEND OF SURFICIAL DEPOSITS ALONG MACKENZIE RIVER VAL **RECENT** NONGLACIAL DEPOSITS** PEATLAND ENVIRONMENT** ORGANIC DEPOSITS: Moinly peot, some work; financook, morehas, and swomps** **FLUVIAL ENVIRONMENT** FLUVIAL ENVIRONMENT** FLUVIAL ENVIRONMENT** FLUVIAL ENVIRONMENT** FLUVIAL ENVIRONMENT** FLUVIAL ENVIRONMENT** FLUVIAL Fan And ENVIRONMENT** FLUVIAL Fan And Cone Deposits** In the lower reaches of flood-prolated portions of flood-prolated in the province of flood-prolated properties of flood-prolated prolated properties of flood-prolated properties of flood-prolated prolated properties of flood-prolated prolated prolate	ridges and mounds; with minor sit, fill, and boulders occurring as inclusions and average occurring as inclusions and average. GLACIAL ENVIRONMENT HUMMOCKY MORAINE DEPOSITS (includes a thin cover of fine-grained wateriold and windied deposits locally and saddeness hearth portly pedral and superiors and sediments beneath portly pedral and superiors. The sediments beneath portly pedral and superiors are sediments beneath portly pedral and superiors. The sediments are sediments beneath portly pedral and superiors are sediments beneath portly pedral and superiors. The sediments are sediments beneath portly pedral and superiors and superiors. The sediments are sediments beneath portly pedral and superiors. The sediments are sediments and superiors and superiors are sediments and superiors. The sediments are sediments and the form plateout, Monthly sit and sand over till and superiors. The sediments are sediments and superiors are the slopes of the superiors in colors. The sediments are sediments and superiors. The sediments are sediments and superiors are sediments and superiors. The sediments are sediments and superiors are sediments and superiors. The sediments are sediments and superiors are sediments and superiors. The sediments are sediments and superiors are sediments and superiors. The sediments are sediments and superiors are sedim



TRAIL RIVER

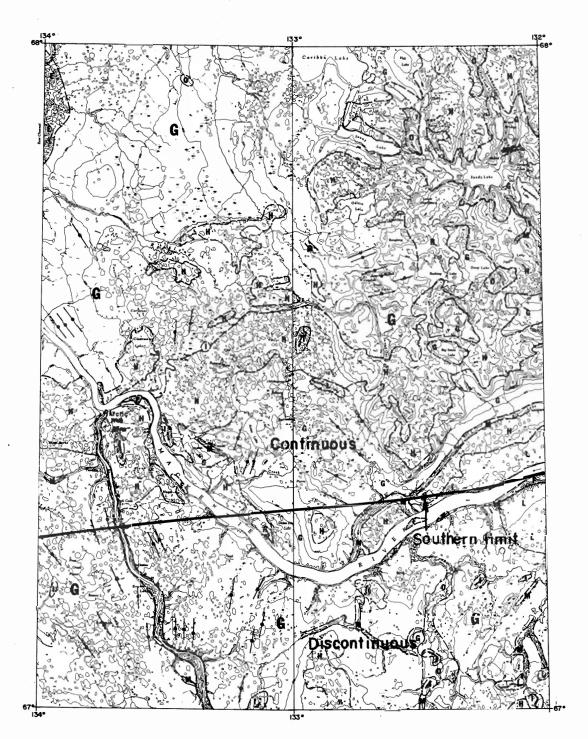




FORT McPHERSON

RECONNAISSANCE SURFICIAL GEOLOGY MAP





ARCTIC RED RIVER

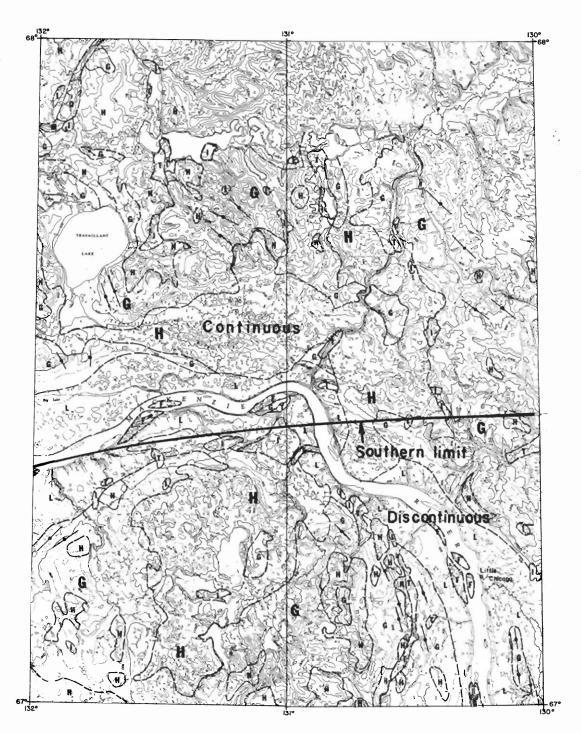
RECONNAISSANCE SURFICIAL GEOLOGY MAP



- DUNE DEPOSITS: Mainly fine sand, silty fine sand
- and on the wooded insolve in Modelen its robust of the Modelen its robust of 160 dollars, in the Modelen in the lower reaches of 161 dollars, in the lower reaches of 161 dollars, in the Modelen in the lower reaches of 161 dollars, in the Modelen in the Mo
 - CEPOSITS: Moinly silt, doysystit, and surry cloy over till

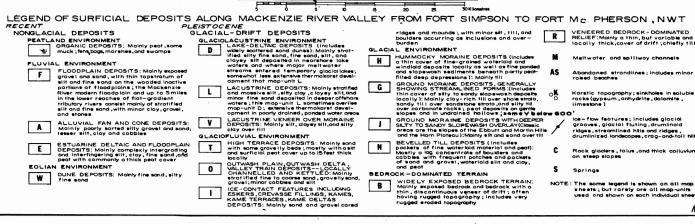
 QLACIOFLUVIAL ENVIRONMENT

 To discover till beds mostly with ostat with some grovel by beds mostly with ostat with some grovel by beds mostly with ostat locally of surficiol ped cover up to 15 feet this locally of surficiol ped cover up to 15 feet this locally of surficiol ped cover up to 15 feet this locally of surficion of surficiol ped covers of the surficion of surfic
- Karstic tapography; sinkholes in solu rocks (gypsum, onhydrite, dolomite, limestone)
- over componer racks, part deposition of the provided of the pr



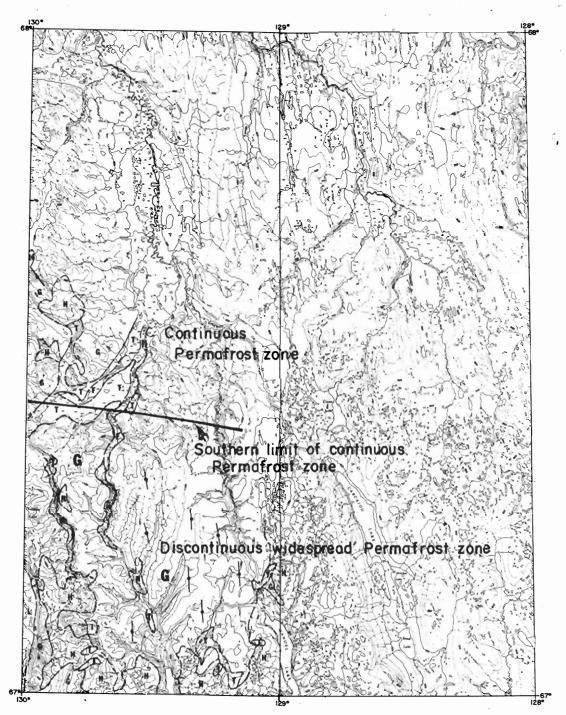
TRAVAILLANT LAKE

RECONNAISSANCE SURFICIAL GEOLOGY MAP



- A LLUVIAL FAN AND CONE DEPOSITS:
 Moinly poorly sorted sitty grovel and sand;
 lesser sitt, clay and cabbles
- BEVELLED TILL DEPOSITS (Includes pockets of fine waterlaid material and poot): Mostly a lag consentral of boulders and cobbles with frequent potches and packets of sond and grover, wateriald silt and clay, and peat ESTUARINE DELTAIC AND FLOODPLAIN DEPOSITS: Moinly complexly intergrading and interfringering elit, clay, fine sand, and pest with commonly a thick peat cover E EOLIAN ENVIRONMENT
- W DUNE DEPOSITS: Mointy fine sand, sitty fine sand
- BEDROCK DOMINATED TERRAIN B WIDELY EXPOSED BEDROCK TERRAIN:
 Mainly exposed bedrock and bedrock with a
 hin, discontinuous vegeer of drift; often
 hoving rugged topography; includes very
 rugged ended topography
- Rock gladers , tolus , and thick colle on steep slopes Springs NOTE: The same legend is shown an all map sheets; but rarely are all map-units used and shown on each individual sheet

ice—flow features; includes glacial graaves, glacial fluting, drumlinoid ridges, streamlined hits and ridges, drumlinized landscapes, crag—and-toil hits



CANOT, LAKE

RECONNAISSANCE SURFICIAL GEOLOGY MAP



LEGEND OF SURFICIAL DEPOSITS ALONG MACKENZIE RIVER VALLEY FROM FORT SIMPSON TO FORT Mc PHERSON, NWT

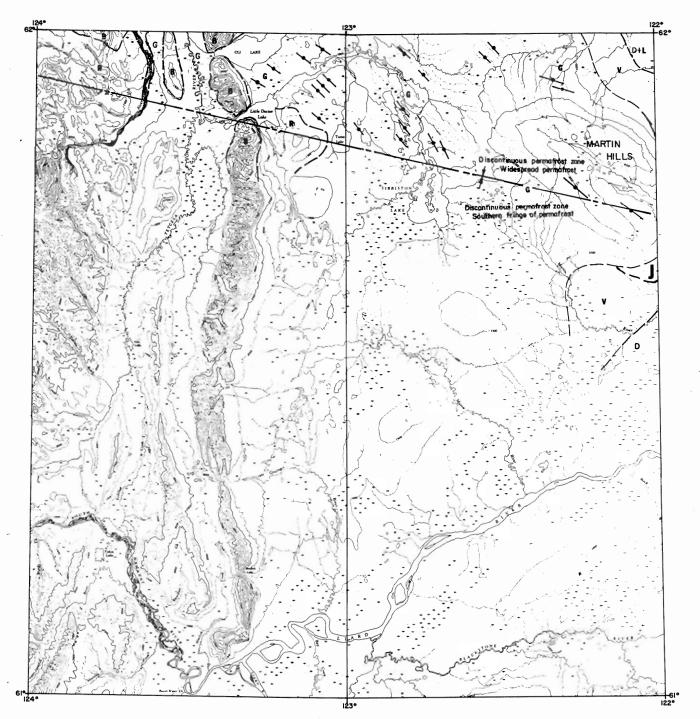
RECENT

NONGLACIAL DEPOSITS**

OF ACID ACID ACID PRINT DEPOSITS**

OF A filled deep depressions): Moliny till

GROUND MORAINE DEPOSITS, GENERALLY
SHOWING STREAMLINED FORMS (Includes
thin cover of sity to sondy stopewash deposits
locally): Moliny clay-right fill over shole stroto,
sandy till over sandstone stroto, and sity till
over corbonole rocks; padi deposits on genits
over corbonole rocks; padi deposits of the stroto
SLTY TO SANOY SLOPEWASH OVERLAY(Closic)
ord the Horn Plateou; Moliny sit and sand over to
BEVELLED TILL DEPOSITS (Includes DUNE DEPOSITS: Moinly fine sand, silty fine sand



SIBBESTON LAKE

SURFICIAL HYDROGEOLOGY MAP RECONNAISSANCE

GENERALIZED HYDROGEOLOGY MAP OF SURFICIAL DEPOSITS ING GROUND-WATER PROBABILITY ALONG MACKENZIS SIVER VALLEY FORT SIMPSON TO FORT McPHERSON, NORTHWEST TERRITORIES

(Note: Estimates of yield are probable, not absolute, maximum figures, which also exclude possible burked bedrock valleys partly filled with granular strata but having no surface expression)

Explanation

- Explanation

 PROPERLY LOCATED, DEVELOPED AND CONSTRUCTED INDIVIDUAL WATER WELLS

 MAY YIELD UP TO 50 TO 100 IOPH AND LOCALLY, IN MICKER WORF PERMEABLE ADULTERS, 100 IO 300 IOPH AND LOCALLY, IN MICKER WORF PERMEABLE ADULTERS, 100 IO 300 IOPH GROUP GRALITY WATER POTENTIALLY

 and tomen, and industries especially those thick coarse aquifers
 in major river valleys tributary to the Mackenzie River. Consists
 in major river valleys tributary to the Mackenzie River. Consists
 individed and and grave below the active and wonded in

 active) floodplains and below coarse sandy and gravelly point-bar

 deposits on sceper-gradent sections of larger meamfering rivers.

 Considerable test drilling may be required to locate large aquifers
 in the lower reaches of tributaries and in the Mackenzie River flood
 plain. Chief well installation problems are flooding and excessive
 lateral and vertical river erosion. Rivers with headwaters in the
 Mackenzie Mountains are extremely flashy and floods can be highly
 destructive.
- OF SMO AND TAIL WILLIAM POPER AND CONSTRUCTED INDIVIDUAL WATER WELLS

 O,T PROPERTY JOCATED, DEVELOPED AND CONSTRUCTED INDIVIDUAL WATER WELLS

 SEDIMENT ARE WIN 2021 AND CONTINUALLY RECURSORD, BETTER PROSPECTS

 OCUT SOUTH OF NORMAN WELLS, ESPECIALLY THICKER LOW-LYING SECTIONS

 OF SAND AND GRAVEL COVERED BY JACATURE, WHITE SPUECE, BALSAM POPLAR,

 AND TAIL WILLIAMS Potentially fair to good possibilities for towirst

 camps, domestic use (washing, drinking) at construction camps, and

 small native settlements. Consider mainly of sandy outwash and ter-

race deposits containing minor gravelly and silt interbeds.

race deposits containing minor gravelly and silt interbeds.

A,C PROPERLY LOCATED, DEVELOWED, AND CONSTRUCTED INDIVIDUAL WATER WELLS E.D MAY YIELD UP TO 5 IGNO PY POOR TO FAIR QUALITY WATER, BETTER PROSPECTS (COMPONIN MAP-UNITS A AND I) OCCUR IN LOCALITIES THAT BORDER W. WATER, ARE FREQUENTLY PLOODED, OR ARE SITURATED ON SOUTH-FACING EXPOSURE. Detertally poor to locally fair water supplies for domestic use. Deteited airphoto study coupled with thorough field geological recommandsmance is needed to pinpoint preferred testhole-exploration fairs. Expect limited ground-water recharge. Cround water vill likely requires some treatment, such as removal of from and manganese. The more promising well sites are commonly restricted to places on active distributaries and abandomed channels on larger alluvial and colluvial fams marked A and C, the margins of larger ponds and creekbeds in areas marked E and D, and south-facing slopes on highest larger ordered recharge.

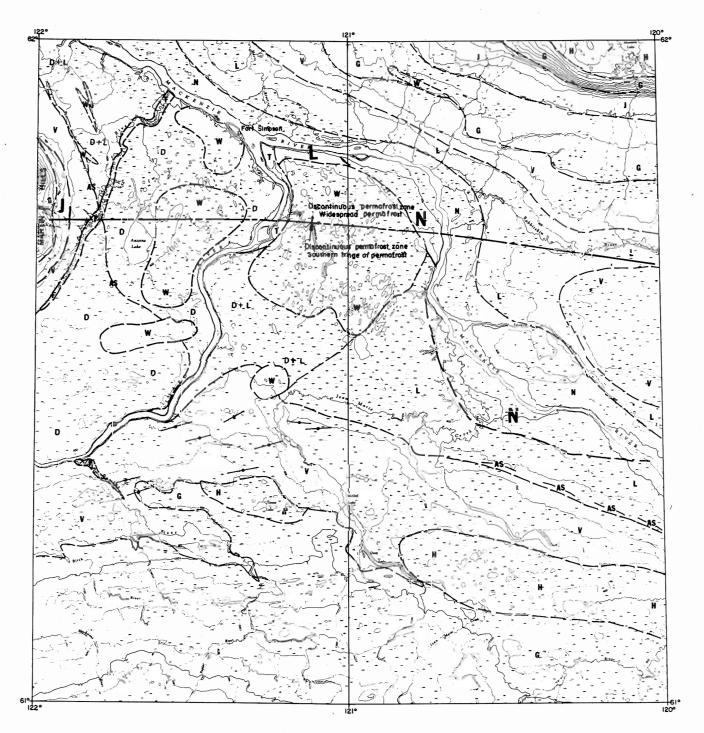
L, VINDIVIDUAL WELLS ARE EXPECTED TO VISID LESS THAN 1 IGPM OF POOR
L, QUALITY WATER Generally poor ground-water sources for all prosM, G QUALITY WATER Generally poor ground-water sources for all prosM, S to large the state were because of low permeability, low recharge
M, AS to large the translater features — smilly in map-units L and H.
S to large the translater features — smilly in map-units L and management of the content of the smill of the smill

B,R,K YIELDS FROM FROFELLY LOCATED, DEVELOPED AND CONSTRUCTED INDIVIDUAL WATER WELLS ARE REPECTED TO WAST FROM LESS THAN 1 10PM IN THICK SHALE SEQUENCES TO POSSIBLY 250 10PM IN SELECT LOCATIONS IN HIGHLY

- DISTURBED AND FRACTURED NON-MARINE SANDSTONE AND POROUS CARBONATE BOCKS AND IN THICE INCOMPATE TERTIARY SAND AND GRAVEL (SEE, ALSO, THE ACCOMPANING CATEFALLID BEDROCK WEMPOSCENIOUS WAY lighly ear lable ground-water source, both from the standards of water quality and quantity. Potentially suitable for demestic supplies, villages and some industries in certain localities.
- S SPRINGS YELDING LAMED (ANATITIES OF HIGHI VARIABLE GUALITY CROUND WATER Generally springs occur in lowland areas along valley banks where perseable soil or rock materials overlie impermeable arta. The springs may be arrestan or water-table. Potentially suitable for towns, industries, and construction campsites depending on water quality.
- INDIVIDUAL WELLS IN ORGANIC (PEAT) DEPOSITS ARE EXPECTED TO YIELD LESS THAN 1 IGPN OF POOR QUALITY WATER Cenerally poor water supplies for all users because of the typical tea colour of the water, potentially high manganess and iron contents and common boggy taste and odour. Includes fens, boggs, markes, and swapps. Cenerally satterned fens are unfrozen is vicinity of Fort Suppon whereas only the small, roundish, treeless collapse scars in peat plateaus are unfrozen.

Lake PROPER INTAKES INTO LARGE LAKES MAY YIELD UP TO 100 IGPM OF GOOD QUALITY WATER; DEPTH OF WATER (PREFEARLY OVER 10 FEST) AND SIZE OF LAKE ARE INTOFERNT CONSIDERATIONS, THE LAKES AND METHE LAKES BEING BETTER Consists of larger and deepst personnel lakes in Mackenzie River Valley upland, such as Tate and Stevart Lakes. Presentially fair to good water supplies for villages, industries, and construction campa. Treatment for Iron, mangemene, and construction campa. Treatment for Iron, mangemene, and organic matter may be necessary. Because of potentially thick ice cover on smaller shallow lakes, the availability of this water source may vary seasonally. Map !

Map 1



FORT SIMPSON

RECONNAISSANCE SURFICIAL HYDROGEOLOGY MAP

GENERALIZED HYDROGEOLOGY MAP OF SURFICIAL DEPOSITS
SHOWING GROUND-WATER PROBABILITY ALONG MACKENZIE RIVER VALLEY
FORT SIMPSON TO FORT M-PHERSON, NORTHWEST TERRITORIES

Estimates of yield are probable, not absolute, maximum figures, h also exclude possible buried bedrock valleys partly filled with granular strata but having no surface expression) (Note: . which

Explanation

- EXPLANATION

 FROPERLY LOCATED, DEVELOPED AND CONSTRUCTED INDIVIDUAL WATER WILLS

 MAY YIELD UP TO SO TO 10 IGHN AND LOCALLY, IN THICKER MORE FROME

 ARLE AQUIFERS, 100 TO 500 IGHN OF COOD HUALITY WATER Poter steally
 good water supplies for tourists and construction campa, will lages
 and tooms, and industries especially those thick coarse squifers
 in major river valleys tributary to the Mackenzie River. (Considerable
 andiny of alluvial sand and grovel below the active and wooded that
 cative) floodplains and below coarses sandy and gravelly point-bar
 deposits on steeper-gradient sections of larger meandering rivers.
 Considerable test drilling may be requised to locate large aquifers
 in the lower reaches of tributaries and in the Mackenzie River flood
 plain. Onlef well installation problems are flooding and excession
 plain. Their well installation problems are flooding and excession
 lackenzie Mountains are etremely flashy and floods can be kighly
 destructive.
- destructive.

 9. T PROPERTY LOCATED. DEVILORD AND CONSTRUCTED NOIVIDUAL MATTA WELLS
 MAY YIELD UP TO 25 KORN OF GOOD QUALITY WATE MERRE THE SE CANULAR
 SEDIMENTS ARE UNFROZEN AND CONTINUALLY RECUMENCE, BETTER PROPERTS
 OCCUR SOUTH OF NORMAN WELLS, ESPECIALLY TRICKER LOW-LYI NO SETTONS
 OF SAND AND GRAVEL COVERED BY JACKPINE, MITTES PRUCE, BALLAN POPLAR,
 AND TALL WILLOWS FORENTIALLY fair to good possibilities for tourist
 camps, domestic use (washing, drinking) at construction camps, and
 small native settlements. Consists mathly of sandy outwash and ter-

race deposits containing minor gravelly and silt interbeds.

- race deposits containing minor gravelly and silt interbeds.

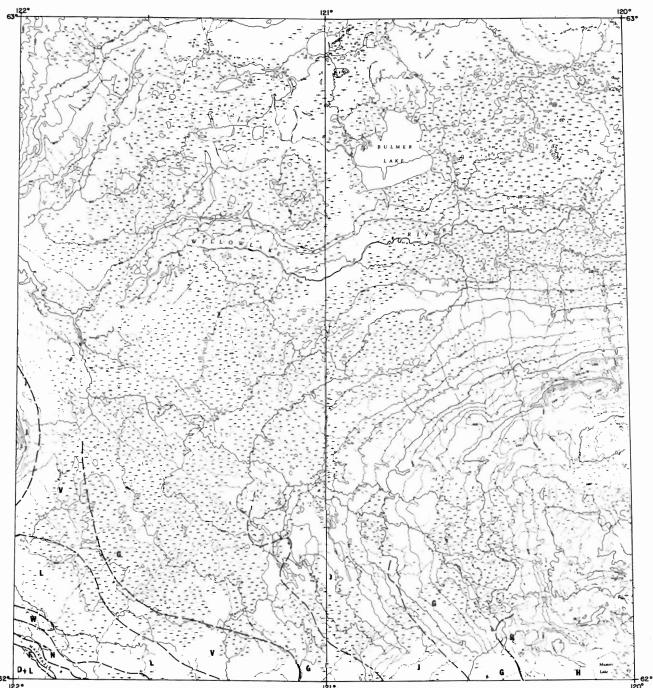
 A, C PROPERLY LOCATED, DEVELOPED AND CONSTRUCTED INDIVIDUAL WATER WELLS

 BY CHAIL NO WAS FORM OF FORM TO FAIR QUALITY WATER, BETTER NOS
 BY THE CONSTRUCTIVE TO THE CONSTRUCTIVE OF THE STATE ROCK TO THE THE THE PROPERTY OF THE MEMBERS. THE DOT THE PROPERTY OF THE MEMBERS OF THE PROPERTY OF THE MEMBERS OF THE PROPERTY OF THE MEMBERS OF THE PROPERTY OF recharge.
- L VINDIVIDUAL WELLS ARE EXPLICITED by YIELD LESS THAN 1 IGPM OF POOR IN GUALITY WATER Generally! poor kound-water sources for all prospective water users becomes of join permeability, low recharge in possibilities, and a high parmetrost table. Recharge is limited M.AS to larger thereoferst features mainly in map-units L and H. Exprict subplace witers having ptentially high from and manganese contients. Commains units) of fine-grained, low-permeability lacustrians and till deposits; the litter containing minor and randomly occurring includings of sand say, less commonly, gravel. Expect subsidial to be wielly frourt (permetrost).
- B,R,K YIELS FROM PROPERLY LOCATED, DEVELOPED AND CONSTRUCTED INDIVIDUAL WATER WELLS ARE EXPECTED TO VARY FROM LESS THAN 'A AMORT LA WALLE SHALL SEQUENCES TO POSSIBLY 250 IGPM AT SELECT 10-ACTIONS IN MICHIEVE

- DISTURBED AND FRACETURES. TORK. THREATHE SAMESTORE AND FOR DUS CARBORATE ROCKS AND IN THICK UNCERSETED TEXTLARY SAME AND GRAVEL (SEE, ALSO, THE ACCOMPANYING GENERALIZED BEDDOCK STRUMDCHOOLDY, MAY, TRIGHT-LIBER LEVEL AND STRUMDCHOOLDY, MAY, TRIGHT-LIBER LEVEL AND ARTHUR AND A
- SPRINGS YIELDING LARGE QUANTITIES OF HIGHLY VARIABLE QUALITY GROUND WATER Cenerally springs occur in lowland areas along valley banks where permeable soil or rock materials overlie in permeable strat, The springs may be artesian or vater-table. Pore: Vially suitable for towns, industries, and construction campsites depending on with er quality.
- BIOLITY.

 INDIVIDUAL WELL IN ORGANIC (PEAT) DEPOSITS ARE EXPECTED TO YIEL, LESS TRAN 1 1671 OF POOR QUALITY WATER Cenerally poor water supplies for all us ere because of the typical tes evides of the water, potentially high memanese and iron contents and channo bogy tasts and odour. In class tens, bogs, matthes, and swamps, Generally patterned fens are unfrozen in vicinity of Fort Simph, recreas may be small, roundish, treeless collapse same in the plateaum are unfrozen.

Map 2



BULMER LAKE

SURFICIAL HYDROGEOLOGY MAP RECONNAISSANCE

GENERALIZED HYDROGEOLOGY MAP OF SURFICIAL DEPOSITS
SHOWING GROUND-WATER PROBABILITY ALONG MACKENZIE RIVER VALLEY
FOR SINGLON TO FORT McPHERSON, NORTHWEST TERRITORIES

(Note: Istimates of yield are probable, not absolute, maximum figures, which also exclude possible buried bedrock valleys parely filled with granular strata but having no surface supression)

LEGEND

Symbol .

Explanation

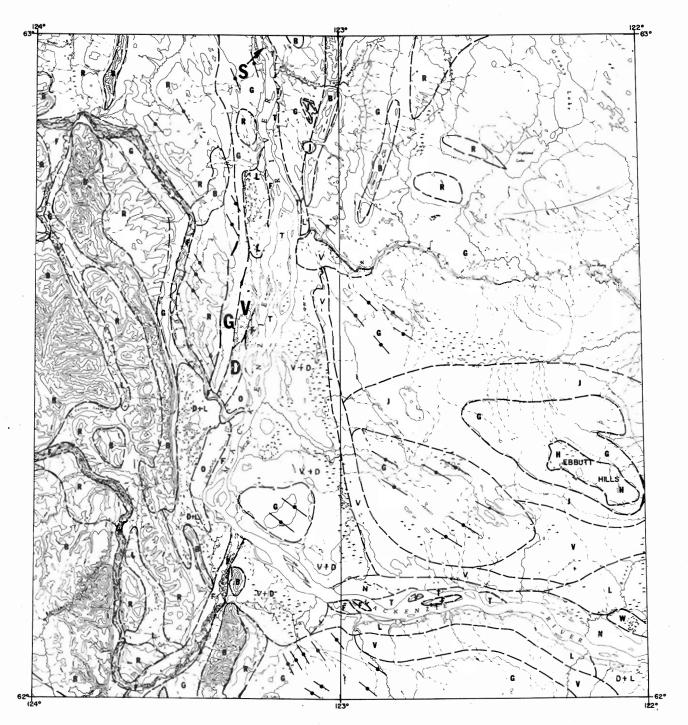
- FPROPERLY LOCATED, DEVELOPED AND CONSTRUCTED INDIVIDUAL WATER WELLS
 MAY YIELD UP TO 50 TO 100 IGPM AND LOCALLY, IN TROCKER MORE PERMEABLE AQUIFERS, 100 TO 500 IGPM OF GOOD QUALITY WATER. Potentially
 good water amplies for towists and construction camps, villages
 and towns, and industries especially those thick coarse aquifers
 in major river valays tributary to the Mackense fiver. Consists
 mainly of alluvial send and gravel below the active and wooded (inactive) floodplain; and below coarse sandy and gravel by point-bar
 deposits on steepergradient sections of larger membering rivers.
 Considerable test crilling may be required to beat large aquifers
 in the lower reaches of tethuraries and in the Mackensie River flood
 plain. Onlief well installation problems are flooding, and excessive
 lateral and vertical river recision. Rivers with headwarters in the
 Mackensie Mountains are extremely flashy and floods can be highly
 destructive.
- O.T. PROPERLY LOCATES, ENVILORED AND CONSTRUCTED INDIVIDUAL WATER WELLS MAY YIELD UP TO 15 (cm or COOD QUALITY WATER WHERE TREES CRANULAR SEDIMENTS ARE DETECTS AND CONTRIBUALLY RECURRENCE, BETTLEN PROSPECTS OCCUR SOUTH OF SOURCE BY JACKTER, WHITE SPRUCE, BALSAM POPLAR, AND TALL WILLOWS Fotentially fair to good possibilities for tourist camps, domestic use (washing, drinking) at censtruction camps, and small native settlements. Consists mainly of sandy outwash and ter-

race deposits containing minor gravelly and silt interbeds.

- race deposits containing minor gravelly and silt interbeds.

 1. PROPERLY LOCATED, DEVELOPED AND CONSTRUCTED INDIVIDUAL WATER FRIENDAM PROPERTY LOCATED, DEVELOPED AND CONSTRUCTED INDIVIDUAL WATER FROM THE PROPERTY LOCATED, WATER, BITTATE AND THE PROPERTY LOCATED, WATER, BATER FROM THE PROPERTY LOCATED, WAS THATED AS SOUTH-FACING. FEVO-SWATER, ARE PROQUENTLY HOODED, OR AME STRUATED SOUTH-FACING. FEVO-SWATER, ARE REQUESTED THOODED, OR AME STRUATED AS SOUTH-FACING. FEVO-SWATER, ARE REQUESTED AS THE PROPERTY LOCATED AS THE PROPERTY L
- L VINDIVIDUAL WELLS ARE EXPECTED TO YIELD LESS THAN 1 16PM OF POOR H GUALITY WATER Generally poor ground-water sources for all prospective water users because of low permeability. Now recharge poctive water users because of low permeability. Now recharge M. J possibilities, and a high permefrost table. Recharge is lixaced M. As to larger thermokarst features nainly in map-units L and H. As to larger thermokarst features—andly in the point of the management contents. Consists mainly of fine-grained, low-permeability lacustries and till deposits, the latter containing minor and randomly occurring inclusions of sand and less :commonly, gravel. Expect subsetle to-be videly frame (permafrost).
- B,R,K YIELS FROM PROPERLY LOCATED, EVYLOUE AND CONSTRUCTED INDIVIDUAL WATEL WELLS ARE EXPECTED TO VARY FROM LESS THAN 1 IGPH IN THICK SHALL SEQUENCES TO POSSIBLY 250 IGPH AT SELECT LOCATIONS IN HIGHLY

- DISTURDED AND FRACTURED NON-MARKE EARDSTONE AND FORDUS CARBONATE BOOSS NOW TO THICK UNCLUMENTED TENTIANS HAND AND GRAFFE (SEE, ALSO, THE ACCOMPANYING CHEVALIZED BEDROCK PRODOCEDOES MAP) Highly variable ground-vater neuros, both from the standpoints of water qua-lity and quantity. Potentially suitable for domestic supplies, villages and none industries in certain localities.
- S SPRING YILLDING LARCE (QUANTITIES OF HIGHIY VARIABLE QUALITY GREEND WATER Generally springs occur in localed aceas along valley banks where perseable soil or rook naturals overlie imperseable strata. The springs may be artesian or vacer-table. Towninially suitable for towns, industrians, and construction compatites depending on water quality.
- The Individual wells in ORGANIC ("TAT) DEPOSITS ARE EXPECTED TO YIELD LESS THE 1 IGPH OF POOR QUALITY WATER Generally poor water supplies for all users because of the typical iss color of the vater, potentially high manganess and from convocute and common boggy tasts and odour. Includes fens, bogs, marshes, and swamps. Generally patterned fens are unfrored in vicinity of over 5 simpson whereas only the small, roundish, treeless collapse scarp in peat plateaus are unfrozen.
- PROPER INTAKES INTO LARGE LAKS MAY YIELD UP TO DO IGHT OF GOOD QUALITY WATER; DEPTH OF WATER (PRITEMEN OVER 10 FRI) AND SIZE OF LAKE ARE INFORTANT CONSIDERATIONS, was assensed above the substitution of the



CAMSELL BEND

RECONNAISSANCE SURFICIAL HYDROGEOLOGY MAP

GENERALIZED HYDROGEOLOGY MAP OF SURFICIAL DEPOSITS
SHOWING GROUND-MATER PROBABILITY ALONG MACKENZIE RIVER VALLEY
FORT SIMPSON TO FORT MATHERSON, MORTHWEST TERRITORIES

(Note: Estimates of yield are probable, not absolute, maximum figures, which also exclude possible buried bedrock valleys partly filled with granular strata but having no surface expression)

LEGEND

Symbol

Explanation

- PROPERLY LOCATED, DEVELOPED AND CONSTRUCTED INDIVIDUAL MATER WELLS
 MAY VIELD UP TO 50 TO 100 IGPH AND LOCALLY, IN THICKER WOLF PERGABLE ADULTES, 100 TO 50 IGPH OF GOOD UNLITY WATER Petentially
 good water supplies for tourist and construction camps, villages
 and towns, and industries especially those thick coarse acquifery
 in major river walkeys tributary to the Mackenzie River. Comsists
 mainly of alluvial sand and gravel below the active and wooded (inactive) floodplains and below coarse sandy and gravelly point-bar
 deposits on steeper-gradient sections of larger semadering rivers.
 Considerable test drilling may be required to locate large aquifers
 in the lower reaches of tributaries and in the Mackenzie River flood
 plain. Chief well installation problems are flooding and excessive
 lateral and vertical river erosiens. Havers with headwaters in the
 Mackenzie Mountains are extremely fleshy and floods can be highly
 destructive.
- O.T. PROPERLY LOCATED, ENVILOPED AND CONSTRUCTED INDIVIDUAL WATER WELLS
 O.T. PROPERLY LOCATED, ENVILOPED AND CONSTRUCTED INDIVIDUAL WATER WELLS THREE CRASHLAR
 SEDIMENTS ARE INPROCED AND CONTINUALLY RECURRING ENTER PROSPECTS
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 OF SAND AND CRAFFL COVERED BY JACKPIEW, WHITE SPRUCE, BALSAN OPELAR,
 AND TALL WILLDER POTENTIALLY fair to mood possibilities for tourist
 camps, domestic use (washing, detection) at construction camps, and
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race deposits containing minor gravelly and silt interbeds.

- L, VINDIVIDIAL WELLS ARE EXPECTED TO YIELD LESS THAN 1 ICPM OF POOR L, GRALITY MATER Generally poor ground-water sources for all property. The property of the
- B,R,K YIELDS FROM PROPERTY LOCATED, DEVELOPED AND CONSTRUCTED INDIVIDUAL WATER WELLS ARE EXPLICITED TO WARY FROM LESS THAN 1 TOPM IN TRICK SHALE SEQUENCES TO POSSIBLY 250 TOPM AT SELECT LOCATIONS IN HIGHLY

DISTRIBUTED AND FRACTURED NOW-MARINE SANDSTONE AND DOROUS CARBONATE ROLES AND IN THICK UNCLUMENTED TRETTARY SAND AND GRAVEL (SEE, ALSO, THE ACCOMPANYIDE GENERALIZED BESSOCK WIPROGEOLOGY HAP) Highly variable grunnd-water source, both from the standpoints of water quality and quantity. Potentially suitable for decestic supplies, villages and some industries in certain localities.

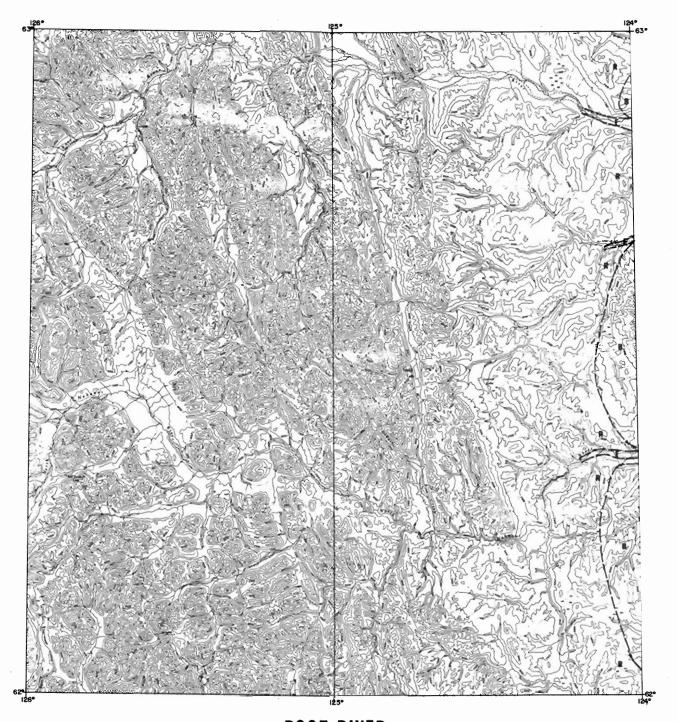
- S SPRINGS THEODIG LARGE QUANTITIES OF RIGHLY VARIABLE QUALITY GROUND WATER Comerally springs occur is localed areas along valley banks where permeable soil or rock materials owerlie impermeable stratuments. The springs may be accessed or water-table. Potentially switchle for towns, industries, and construction campattes depending on water quality.
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 EISS THAN 1 IOPM OF POOR QUALITY WATEX Generally poor water supplies for all weers because of the typical rea colour of the water, potentially high managemes and Iron contents and common beggy taste and adour. Includes fews, begg in the property of the water potentially high managemes and Iron contents and common beggy taste and adour. Includes fews, begg in the property of the content of the property of the
- Zen.

 Lake PROPER INTAKES INTO LARGE LAKES MAY YIELD UP TO 100 IGPM OF GOOD QUALITY WATER; DEPTH OF WATER (PREFERABLY OVER 10 FEET) AND SIZE OF LAKE ARE IMPORTANT CONSIDERATIONS, THE LAKGER AND DEEPER LAKES BILDED BITTER.

 TER Commists of larget and deeper permanent lakes in Mackemise River Valley upland, such as Tate and Stewart Lakes. Potentially fair to good water supplies for villages, industries, and construction campa. Treatment for Iren, mangamese, and organic matter may be necessary. Because of potentially thick (see cover on sublier shalles) lakes, the availability of this Water mource may vary seasonally.

 May 4



ROOT RIVER SURFICIAL HYDROGEOLOGY MAP RECONNAISSANCE

GENERALIZED HYDROGEOLOGY MAP OF SURFICIAL DEPOSITS
SHOWING GROUND-MATER PROBABILITY ALONG MACKENZIE RIVER VALLEY
FORT SIMPSON TO FORT MEPHERSON, NORTHWEST TERRITORIES

(Note: Estimates of yield are probable, not absolute, maximum figures, which also exclude possible buried bedrock valleys partly filled with granular strata but having no surface expression)

LEGEND

Explanation

- Explanation

 PROPERLY LOCATES, BUYLOPED AND CONSTRUCTED INDIVIDUAL WATER WELLS
 MAY YIELD UP TO 50 TO 100 IGPM AND LOCALLY, IN TRICKER MORE PERMEABLE ADULTER'S, 100 TO 500 IGPM OF GOOD QUALITY WATER Potentially
 good water respected to construction camps, villages
 and towns, and industries especially those thick coarse aquifers
 in major river valleys tributary to the Mackenzie River. Consists
 mainly of alluvial sand and gravel below the active and wooded (inactive) floodplains and below coarse sandy and gravelly point-bar
 deposits on steeper-gradient sections of larger meandering rivers.
 Considerable test drilling may be required to locate large aquifers
 in the lower reaches of tributaries and in the Mackenzie River flood
 plain. Chief well installation problems are flooding and excessive
 lateral and vertical river erosion. Rivers with headwaters in the
 Mackenzie Mountains are extremely flashy and floods can be highly
 destructive.
- O,T PROPERTY LOCATED, DEVELOPED AND CONSTRUCTED INDIVIDUAL WATER WELLS MAY YIELD UN TO 15 TOPH OF COOD QUALITY WATER WENNE, THESE GRANULAR SEDIMENTS ARE UNFOCKED AND CONTINUALLY MIGHAGINED. THERE PROSPECTS OCCUR SOUTH OF WORDEN WELLS, ESPECIALLY THEORY AS FRUCE, BALSAN POPLAR, AND TALL WILLOWS PRENETING JET TO 8000 possibilities for tourist camps, domestic use (washing, datonatruction camps, and small naisys sessiblents. Consists mainly of sandy outwash and ter-

race deposits containing minor gravelly and silt interbeds.

race deposits containing minor gravelly and silt interbeds.

A. PROPERLY LOCATED, BUYELPERD AND CONSTRUCTED INDIVIDUAL MATER WEILS

A. WAY YIELD UP NO 5 ICEN OF POOR TO PAIR QUALITY WATER, BETTER PROS
PRICTS (COMENIN NAM-PANITS AND 1) OCCUR IN LOCALITIES THAT ROBER

W. MATER, ARE PROGRETIVE FLOODED, OR ARE SITUATED ON SOUTH-FACING EXCO
SURES Centrally poor to locally fair vater supplies for deposition
use. Detailed airphoto study coupled with thorough field geological
reconnaissance is needed to pinpoint preferred teathole-exploration
sites. Expect limited ground-water Technage. Ground water will likely require some treatment, such as recoval of iron and manganee.
The more promising well sites are commonly restricted to places on
active distributaries and abandomed channels on larger alluvial and
colluvial fans marked A and C, the margins of larger ponds and creekbeds in areas marked E and D, and south-facing alopes on higher larger wooded ridges marked W and I in regional lowland areas receiving
recharges. recharge.

L VINDIVIDUAL WELLS ARE EXPECTED TO YIELD LESS THAN 1 IGPM OF POOR COULTIV WATER Cenerally poor ground-water sources for all prospective water were because of low permeability. Now recharge N. Possibilities, and a high permafrost table. Recharge is limited M. AS to larger thermokers features — mainly in map-mints L and H. Expect sulphate waters having potentially high from and managemene consease. Consists mainly of fine-gradined, low-permeability lacustries and till deposits, the latter containing minor and randomly occurring inclusions of sand and, less commonly, gravel. Expect subsetts to be widely frozen (permafrost).

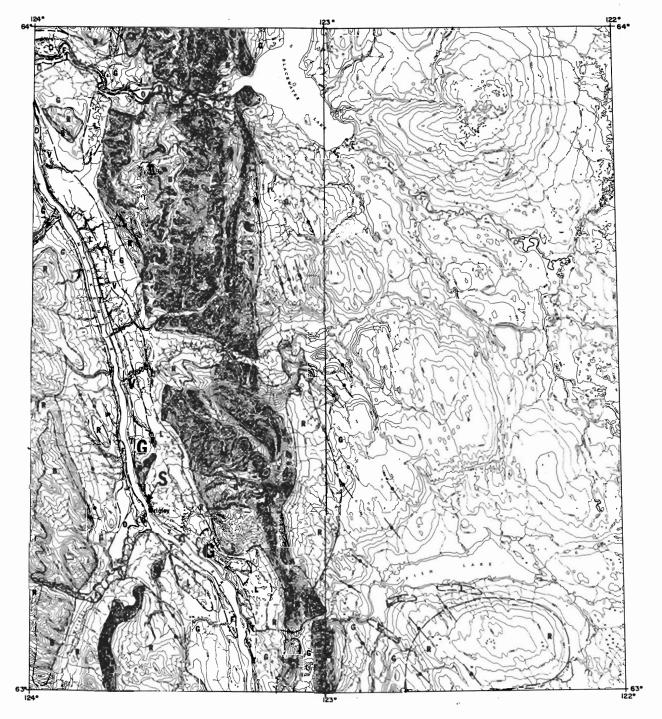
B,R,K YIELDS FROM PROPERLY LOCATED, DEVELOPED AND CONSTRUCTED INDIVIDUAL WATER WELLS ARE EXPECTED TO WARY FROM LESS THAN 1 IGPM IN THICK SHALE SEQUENCES TO POSSIBLY 250 ICPM AT SELECT LOCATIONS IN HIGHLY

DISTURBED AND FRACTURE) NON-MARINE SANDSTONE AND FOROUS CARBONATE ROCKS AND IN THICK UNCHANTED ITERITARY SAND AND GRAVEL (SEE, ALSO, THE ACCOMPANYING CANCELLEED BEBROCK HYPROGROLOGY MAP) Highly variable ground-water source, both from the standpoints of water quality and quantity. Potentially suitable for domestic supplies, villages and some industries in certain localities.

- S SPRINGS YELDING LARGE QUANTITIES OF HIGHLY VARIABLE QUALITY ("MORND WATER Generally springs occur in lowland areas along valley benuls where perseable soil or rock materials overlie inpermeable stratuments of the springs may be artesiam or water-table. Potentially suitable for towns, industries, and Construction campsites depending on various stratum of the stra er quality.
- INDIVIDUAL WELLS IN ORGANIC (PEAT) DEPOSITS ARE EXPECTED TO YIELD LESS THAN 1 IGPN OF POOR QUALITY WATER Cenerally poor water supplies for all users because of the typical tea colour of the water, potentially high manganese and iron contents and common boggy taste and odour. Includes fens, bogs, marshes, and swamps. Cenerally patterned fens are unfrozen in vicinity of Fort Simpson whereas only the small, roundish, treeless collapse scars in peat plateaus are unfrozen.
- Zen.

 Lake PROPER INTAKES INTO LARGE LAKES MAY YIELD UP TO 100 IGPH OF 000D QUALITY WATER; DEPTH OF MATER (PREFERBIN OVER 10 FEET) AND CIZE OF LAKE ARE IMPORTANT CONSIDERATIONS, THIS LAGGE AND DEEPER LAKES EING BETTER Consists of larger and deeper permanent lakes in Sackmire River Valley upland, such as Tate and Stewart Lakes. Potentially fair to good water supplies for villages, industries, and construction camps. Treatment for iron, manganese, and organic matter may be fidenseary. Because of potentially thick for cover on smaller shallow lakes, the availability of this water source may vary seasonally.

 MAGE 5



WRIGLEY RECONNAISSANCE SURFICIAL HYDROGEOLOGY MAP

GENERALIZED HYDROGEOLOT HAP OF SURFICIAL SEPOSIT'S SHOWING GROUND-WATER PROBABILITY ALONG MACKRIZE RIVER VALLEY FORT SIMPSON TO FORT MCHERSON, MORTHWEST TERRITORIES

(Note: Estimates of yield are probable, not absolute, maximum figures, which also exclude possible buried bedrock valleys partly filled buried by the granular strata but having no aurface expression)

LEGEND

Explanation

- Explanation

 PROPERLY LOCATED, DEVELOPED AND CONSTRUCTED INDIVIDUAL WATER WELLS
 MAY YIELD UP TO 50 TO 100 IGPM AND LOCALLY, IN TRICKER MORE PERGEABLE AQUIFERS, 100 TO 500 IGPM AND LOCALLY, IN TRICKER MORE PERGEand towns, and industries specially those thick coarse aquifers
 and towns, and industries specially those thick coarse aquifers
 in major river valleys tribuary to the Mackenzie Hiver. Consists
 mainly of alluvial sand and grawl helow the active and woods! (inactive) floodplains and below environ sandy and grawlly point—bar
 deposits on steeper-gradient sections of larger meandering rivers.
 Considerable test drilling may be required to locate large aquifers
 in the lower reaches of tributaries and in the Mackenzie River flood
 plain. Chief well installation problems are flooding and excessive
 lateral and vertical river erosion. Rivers with headwaters in the
 Mackenzie Nountains are extremely flashy and floods can be wighly
 destructive.

 PROPERLY LOATED. ENTILLIPED AND CONSTRUCTED CONTURNING MARCH.
- PROPERLY LOCATED, DEVILOPED AND CONSTRUCTS ANDIVIDUAL WATER WELLY MAY YIELD UT TO 25 GOM OF GOOD QUALITY MATER MAPPER THESE FRANKLE, SECHIMENTS ARE ENTROMES AND COTINGLALLY RECEMBED. HETER PROSPECT, OCCUR SOUTH OF MORPHA WELLS, SPECIALLY THICKE LOW-LYING SECTION. OF SAND AND EARLY LOWER ED BY LACTIF NO. WHITE SPECIAL ALLAN POPLAR, AND TALL WILLOWS PRESENTED BY LACTIF NO. WHITE SPECIAL ALLAN POPLAR, AND TALL WILLOWS PRESENTED BY LACTIF NO. WHITE SPECIAL ALLAN POPLAR, AND TALL WILLOWS PRESENTED BY LACTIF NO. WHITE SPECIAL ALLAN POPLAR, AND TALL WILLOWS PRESENTED BY LACTIF OF THE WAY AND TALL WILLOWS PRESENTED BY LOCATION OF THE WAY AND TALL WILLOWS PRESENTED BY LOCATION OF THE WAY AND THE WAY AN

race deposits containing minor gravelly and silt interbeds.

- Trace deposits containing minor gravelly and silt interbeds.

 A. P. RROPERI LOCATED, DEVELOPED AND CONSTRUCTED INDIVIDUAL WATER WELLS

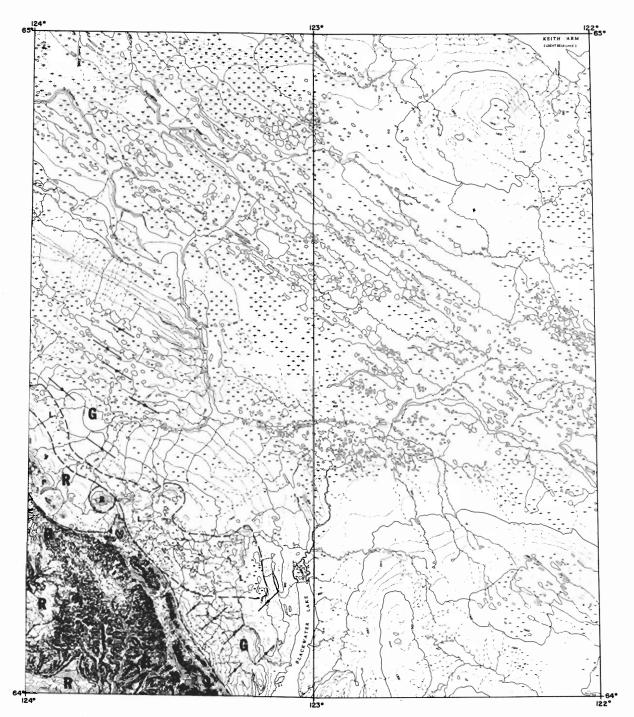
 D.MAYYELD UP TO 5 IGNO FOROR TO PAIR QUALITY MATER; BETTER PROSPECS (COMMONINY MAP-UNITS A AND I) OCCUR IN LOCAL-SIES THAT BORDER

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- D M YIELDS NEW PROPERTY LOCATED DEVELOPED OF CONSTRUCTED INDIVIDUAL MARKET WELLS ARE OFFICED TO WARF FROM LESS THAN I IGPM IN TRAICK SHARL SEQUENCE IN POSSIBLE YES OFFICE A SELECT IDCATIONS IN MIGHLY

- DISTURBED AND FRACTHESN MAN-MARINE SAMMOVANE AND POROUS CARBONATE BOCKS AND IN THIX UNDERSTED INSTITUTE AND AND GRAVEL (SEE, ALSO, THE ACCOMPANYING CATALITY BREACK MAY FEDLORY MAP) Highly variable ground-water source, both from the standpoints of water quality and quantity. Potentially switchel for domestic supplies, villages and some industries in certain localities.

 SPRINGS YIELDAG LAGE QUANTITIES OF HIGHLY VARIABLE QUALITY GROUND WATER Generally springs occur in local and areas along valley banks where permeabs soil as Tock materials overlie inspreadle strata. The springs may be artested or vater-table. Fotely, ally suitable for towns, industries, and construction campaites de pending on water quality.

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BLACK WATER LAKE

SURFICIAL HYDROGEOLOGY MAP RECONNAISSANCE

GENERALIZED HYDROGEOLOGY MAP OF SURFICIAL BUPUSITS
SHOWING GROUND-MATER PROBABILITY ALONG MACHINETE RIVER VALLEY
FORT SIMPSON TO FORT MEPHERSON, NORTHWEST TERRITORIES

ote: Estimates of yield are probable, not absolute, maximum figures, which also exclude possible buried bedrock valleys partly filled with granular strata but having no surface expression)

LEGEND Explanation

FROTERLY LOCATED, DEVELOPED AND CONSTRUCTED INDIVIDUAL MATER WELLS MAY YIELD UP TO 30 TO 100 IGPH AND CONSTRUCTED INDIVIDUAL MATER WELLS MAY YIELD UP TO 30 TO 100 IGPH AND LOCALLY, IN TRICKER MORE PROME AND AND THE STATE OF TO TOURS AND CONSTRUCTED OF THE WARRY SHOWS AND THE STATE OF THE WARRY SHOWS AND T

O,T PROPERLY LOCATED, EVELOPED AND CONSTRUCTED INDIVIDUAL WATER WELLS MAY YIELD UT TO 25 IGPN OF GOOD QUALITY WATER WHERE THESE GRANULAR SEDIMENTS ARE INTRODUCED AND CONTROLLAR RECURSED; BATTLE PROSPECTS OCCUR SOUTH OF MORNAY WELLS, EXPECIALLY TRICKER LOC-LYING SECTIONS OF MADD AND GLAVEL OVERED BY LOCAPE, MITTS SPRUCE, MALENT POPLAR, AND TALL WILLOWS FOTENTIALly fair to good possibilities for tourist camps, domestic use (washing, drinking) at construction camps, and small native settlements. Consists mainly of sandy outwash and ter-

race deposits containing minor gravelly and silt interbeds.

A_C PROPERLY LOCATED, DEVELOYED AND CONSTRUCTED INDIVIDUAL WATER WELLS
E_D MAY YIELD UP TO 5 IGHOUP FOOR TO FAIR QUALITY WATER; BETTER PROSPROTS (COMMENCE MAP-UNITS A AND I) OCCUR IN LOCALITIES THAT BORBLER
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Ly INDIVIDUAL WELLS ARE EXPECTED TO YIELD LESS THAN 1 IGFM OF POOR H, GOULLTY WATER Generally poor ground-water sources for all prospections of the process of the process

B,R,K YIELDS FROM PROPERLY LOCATED, DEVELOPED AND CONSTRUCTED INDIVIDUAL WATER WELLS ARE EXPECTED TO VARY FROM LESS THAN 1 1GPM IN THICK SHALE SEQUENCES TO POSSIBLY 250 1GPM AT SELECT LOCATIONS IN HIGHLY

DISTURNED AND FRACTURED SOM-MARINE SANDSTONE AND POROUS CARBONATE RICKS AND IN THICK DECEMBED INTITIARY SAND AND GRAVEL (SEE, ALSO, TO ACCOUNT AND FRACTURE CONTROLLED MEMORY MYPROGROLOGY MAP Highly variable ground-water source, both from the standpoints of water quality and quantity. Potentially sufficiently sufficient cupplies, villages and some immemorial survivale for domestic supplies, villages and some immemorial survivale.

SPRINGS VILLINGS LANGE (SWATTIZES OF HIGHLY VALUABLE QUALITY GROUND MATER Generally springs secur in levland areas along valley banks where perseable sell a rock materials overliet impermebble strate. The springs may be artesian or water-table. Potentially suitable for towns, industries, and construction campaites depending on water quality.

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INDIVIDUAL WELLS IN ORGANIC (PEAT) DEPOSITS ARE EXPECTED TO YIELD
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for all users because of the typical tea colour of the water, potentially high manganese and from contents and common hogy taste and
odoor. Includes fens, bogs, marshes, and swamps. Centrally patterned fems are unfrozen in violity of Fort Sippson whereas only the
small, roundish, trecless collapse scars in peat plateaus are unfrozen.

Lake PROPER INTAKES INTO LARGE LAKES MAY YIELD UP TO 100 IGPM OF GOOD QUALITY WATER; BEPTH OF WATER (PREFEABLY OVER 10 FEET) AND SIZE OF LAKE AND EXPORATION CONSIDERATIONS, THE LAKER AND DEFERS LAKES BEING BETTE AND STREAM OF THE LAKE AND DEFERS LAKES BEING BETTE AND STREAM OF THE LAKES AND DEFERS LAKES REGISTED AND STREAM OF THE LAKES AND STREAM OF THE AND STREAM OF THE LAKES AND STREAM

Map 8



FORT NORMAN

SURFICIAL HYDROGEOLOGY MAP RECONNAISSANCE

GENERALIZED HYDROGEOLOGY MAP OF SURFICIAL DEPOSITS
SHOWING GROUND-MATER PROBABILITY ALOG MACCOVZIE RIVER VALLEY
FORT SIMPSON TO FORT MCPHERSON, MORTIMEST TERRITORIES

(Note: Estimates of yield are probable, not absolute, maximum figures, which also exclude possible buried bedrock valleys partly filled 4th granular 'strata but having no surface expression)

LEGEND

Explanation

- PROFEST Y LOCATED, DEVELOPED AND CONSTRUCTED INDIVIDUAL MATER WELLS
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 Considerable test drilling may be required to lowest large aquifers
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 plain. Chief well installation problems are flooding and excessive
 lateral and vertical river erosion. Rivers with headwaters in the
 Macemaic Nountains are extremely flashy and floods down
- O.T. PROFILE LOCATED, DEVELOPED AND CONSTRUCTED INDIVIDUAL WATE WILLS
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 SERVENTS AM INTROCEN AND CONTINUALLY RECURSION, INSTITES PROSPICTS
 OCC. CONTINUE NORMAN WELLS, ESPECIALLY THOORY LOCATION, SECTIONS
 OF SAND AND CRIVEL COVERED BY JACKPIR, WITH SITE B. BALAN POPLAR,
 AND TALL WIRESON FORENTIALly fair to good possibilities to courted
 camps, domestic use (washing, drinking) at construction camps, and
 small native settlements. Consists mainly of sandy outwash and ter-

deposits containing minor gravelly and silt interbeds.

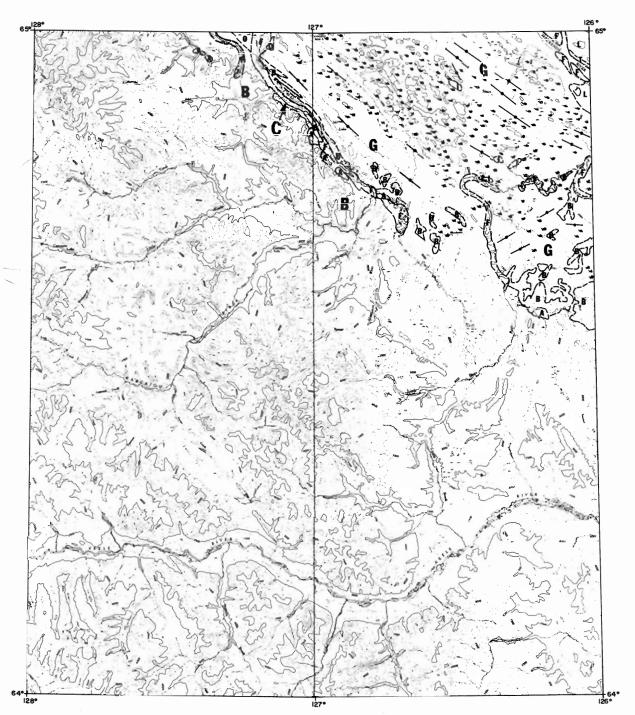
- race deposits containing minor gravelly and silt interbeds.

 A. PROPERLY LOCATED, DEWELDFED AND CONSTRUCTED INDIVIDUAL WATER VELLS
 MMY YIELD UP TO 5 IGHO FO POR TO PAIR QUALITY WATER; BETTER PROSPRICTS (COMPONIN MAR-UNITS A AND I) OCCUR IN LOCALITIES THAT BORDER
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 recommissance is needed to pinpoint prierred teethole-exploration
 sites. Expect limited ground-water release, Ground water vill likely require some treatment, such as rempared from and manganese.
 The more promising well alters are commany restricted to places on
 active distributation and shandomed changes on larger alluvial and
 colluvial fame marked A and C, the more finest produced creekbeds in mean marked a and D, and soutfairs; slopes on higher larger
 er wooded ringes marked W and I in regional localing areas receiving
 recharge. er wooded recharge.
- L VINDIVIDUAL WELLS ARE EXPECTED TO YIELD LESS THAN 1 IGPM OF POOR IN QUALITY WATER Generally poor ground-water sources for all prospective water users because of low permeability, low recharge in Japonsthilties, and a high permafrost table. Recharge is limited M.ASte larger therekarte features mainly in map-units L and H. Expect submids waters having potentially high from and manganese contents. Consists mainly of fine-grained, low-permeability lacustrine and till deposits, the latter containing minor and randomly occurring inclusions of sand and, less commonly, gravel. Expect submodils to be widely frozen (permafrost).
- B,R,K YIELDS FROM PROPERILY LOCATED, DEVELOPING AND CONSTRUCTED INDIVIDUAL WATER WELLS OF DEPETED TO VARY FROM LESS THAN 1 IGPH IN THICK SHALE SEQUENCE TO: POSSIBLY 250 ICPH AT SELECT LOCATIONS IN HIGHLY

DISTRIBUTE AND FROM THE SAME STONE AND POLYMENT SAME AND GRAVEL (SEE, ALSO, THE ACCOUNT ANY INCOMPLETE THE ACCOUNT ANY INCOMPLETE SOUTH A FORECOLOGY MAP. Highly work and quantity. Potentially suitable for domestic suplies, villages and some industries in certain localities.

- SAMESS MUM SOME INDUSTRIES IN CERTAIN localities.

 SHIMOS YHILDING LARGE QUANTILES OF HIGHLY VARIABLE QUALITY GROUND
 WITH Generally springs occur in localed areas along valley b anks
 were permeable soil or rock materials overlie impermeable strets.
 The springs may be a retealed or variet-table. Fortentially satisfable
 for towns, industries, and construction campaites depending on Vater quality.
- INDIVIDUAL WELLS IN ORGANIC (FEAT) DEPOSITS ARE EXPECTED TO YIELD LESS THAN 1 IGFN OF FOOR QUALITY. THE PROPERTY OF THE PROPER
- Lake PROPER INTAKES INTO LARGE LAKES MAY YIELD UP TO 100 IOPH OF GOOD QUALITY WATER; DEPTH OF WATER (PREFERABLY OVER 10 FET) AND SIZE OF LAKE ARE IMPORTANT CONSIDERATION; THE LARGER AND DEPTH LAKES BET NO BETTER CORSISTS of larger and deeper permanent Lakes. Potentially fair to good water supplies for vilpage, is doubtries, and construction campa. Treatment for iron, manganes, and organic matter may be necessary. Brawe of potentially this toc ever on smaller shallow lakes, the anglability of this water source may yeary seasonally.



CARCAJO U CANYON

RECONNAISSANCE SURFICIAL HYDROGEOLOGY MAP

GENERALIZED HYDROGEOLOGY MAP OF SURFICIAL DEPOSITS
SHOWING GROUND-WATER PROBABILITY ALONG MACKENZIE RIVER VALLEY
FORT SIMPSON TO FORT H.PHERSON, NORTHWEST TERRITORIES

otil Estimates of yield are probable, not absolute, maximum figures, widch also exclude possible buried bedrock walleys partly filled with granular strata but having no surface expression)

LEGEND

Explanation

- Explanation

 PROPERLY LOCATED, DEVELOPED AND CONSTRUCTED INDIVIDUAL WATER WELLS
 MAY YIELD UP TO 50 TO 100 IGPM AND LOCALLY, IN THICKER HOME PERMEABLE AQUIFERS, 100 TO 50 Igent of Cond quality WATER Potentially
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 and towns, and industries—exploitably shows the amount villages
 is amount of the condition of the construction of the constructio
- O.T PROPERIN LOCATED, DEVELORD AND CONSTRUCTED INDIVIDUAL WATER WELLS

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 SEDIMENTS ARE UNITIODS AND CONTINUALLY RECOMBAGED BETTS, PROPERLY,
 OCCUR SOUTH OF NORMAN WELLS, EXPECIALLY TRICKE LOW-LOWS SECTIONS
 OF SAND AND GRANEL COVERED BY LOCAPIE, WHITE SPRUCE, MALSAN POPLAR,
 AND TALL WILLOWS Potentially fair to good possibilities for courts'
 camps, dementic use (washing, disking) at construction camps, and
 small native settlements. Consists mainly of sandy outwash and ter-

- race deposits containing minor gravelly and silt interbeds.

 A PROFERLY LOCATED, REVELOPED AND CONSTRUCTED INDIVIDUAL WATER WELLS

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- L V INDIVIDUAL HELIS ARE EXPECTED TO YELD LESS THAN 1 IGPM OF POOR H, QUALITY Wints temerativy poor ground-water sources for all prosH, Quality Wints temerativy poor ground-water sources for all prosH, possibilities, and a high permafrost table. Recharge is limited
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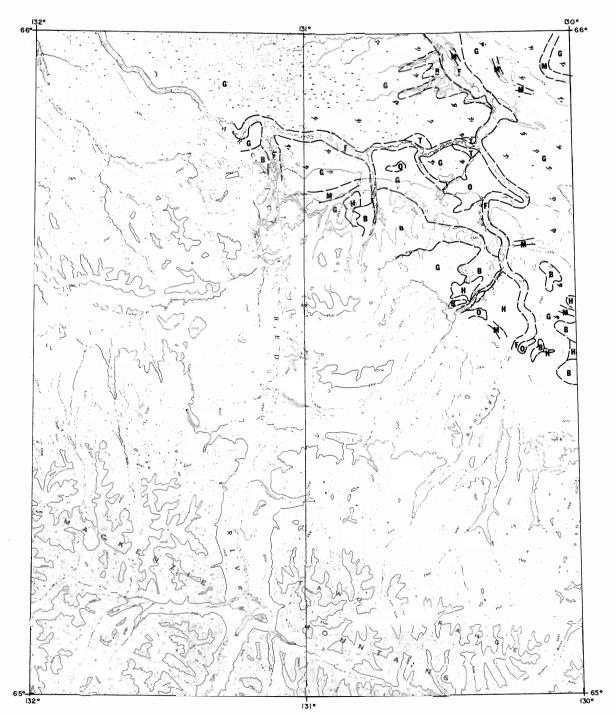
 Expect suphate waters having potentially high iro, and manganese contents. Consists mainly of fine-grained, low-permatoriary lacus
 strine ani till deposits, the latter containing minor and randomly occurring inclusions of saind and, less commonly, gravel. Expect subsolls to be vidaly frozen (permafrost).
- B,R, WYIELS FROM PROPERTY LOCATED, DEVELOPED AND CONSTRUCTED INDIVIDUAL WATER WELLS ARE EXPECTED TO VARY FROM LESS THOM 2 IGEN IN THICK SHALL SEQUENCES TO POSSIBLY 250 IGPN AT SELECT LOCATIONS IN HIGHLY

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- INDIVIDUAL WELLS IN ORGANIC (PEAT) DEPOSITS OF EXPECTED TO YIELD LESS THAN 1 IGPH OF FOOR GALITY MATER Generally peer water supplies for all users because of he typical tea colour of the water, potentially high manganese and from contents and common ungar transmission of the state of the st
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 Valley upland, such & Tate and Size at Lakes. Potentially fair to
 good water supplies by villages, industries, and construction camps.
 Treatment for tron, tempenese, and cyrganic matter may be necessary,
 Because of potentially thick too cover on smaller shallow lakes, the
 availability of this water sewere may vary seasonally.

 Map 10

Map 10



UPPER RAMPARTS RIVER

RECONNAISSANCE SURFICIAL HYDROGEOLOGY MAP

GENERALIZED HYDROGEOLOGY MAP OF SURJICIAL DEPOSITS
SHOWING CROUND-WATER PROBABILITY ALONG MUCKESIE RIVER VALLEY
FORT SIMPSON TO FORT MEPHERSON, NORTHWEST TERRITORIES

ote: Estimates of yield are probable, not absolute, maximum figures, which also exclude possible buried bedrock valleys partly filled with gummular strata but having no surface expression)

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Symbol

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- PROPERLY LOCATED, DEVELOPED AND CONSTRUCTED INSIVIDENAL MATTE WILLIS ANY YIELD UP TO SO TO 10 GPM AND LOCALLY, IN TRICKE MARE FEMBLE-ABLE ACCUPERS, 100 TO 500 LGPM OF GGM COLLITY MATER. Patentially good water supplies for tourists and construction camps, villages and towns, and industries especially those thick coarse aquifers in major river valleys tributary to the Backergis River. Consists 'manily of alluvia's and and gravel below the egitve and wooded (in-active) floodplains and below coarse andy ann gravelly point-bar deposits on steeper-gradient sections of larges meandering rivers. Considerable lears drillings may be required to locate large aquifers in the lower reaches of tributaries and in the Mackenzie River flood plain. Onle well installate my problems are flooding and excessive lateral and rettical river costom. Rivers with headwaters in the Mackenzie Monarais size extractly flashy and floods can be highly destructive.

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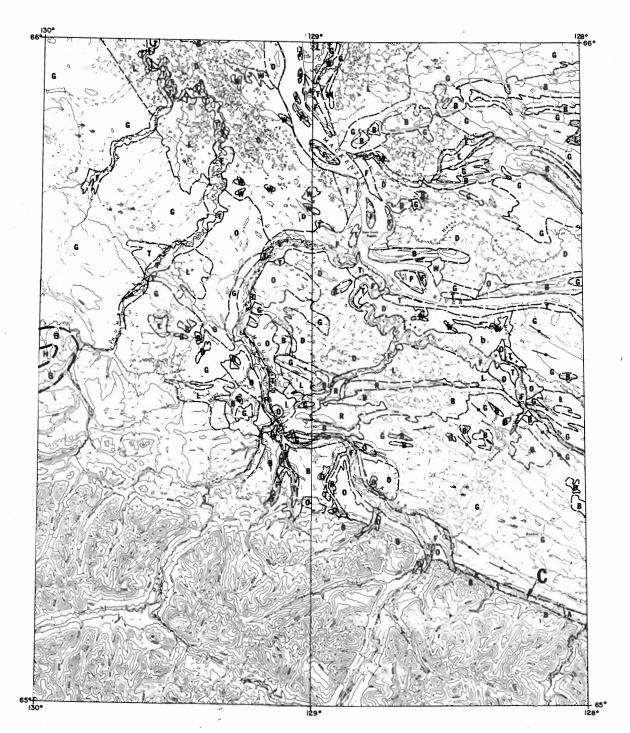
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SURFICIAL HYDROGEOLOGY MAP RECONNAISSANCE

GENERALIZED HYDROGEOLOGY MAP OF SURFICIAL DEPOSITS WING GROUND-WATER PROBABILITY AIRSO PARKETER RIVER VALLEY FORT SIMPSON TO YORK Mapperson, NORTHWEST TERRITORIES

(Note: Estimates of yield are probable, not absolute, maximum figures, which also exclude possible buried bedrock waffers partly filled with gramular strata but having no surface expression)

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- race deposits containing minor gravelly and silt interbeds.

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Map 12



NORMAN WELLS

RECONNAISSANCE SURFICIAL HYDROGEOLOGY MAP

GENERALIZED HYDROGEOLOGY MAP OF SURFICIAL DEPOSITS NING GROUND-WATER PROBABILITY ALONG MACCESTE RIVER VALLEY FORT SIMPSON TO FORT MEPHERSON, NORTHWEST TERMITORIES

(Note: Estimates of yield are probable, not absolute, maximum figures, which also exclude possible buried bedresk valleys partly filled with granular strata but having no surface expression)

- PROPERLY LOCATED, DEVELOPED AND CONTROLLED INDIVIDUAL WATER WELLS
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 deposits on steeper-gradient sections of larger meandering rivers.
 Considerable test drilling may be required to locate large aquifers
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 lateral and vertical river crosion. Rivers with beamsters in the
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race deposits containing minor gravelly and silt interbeds.

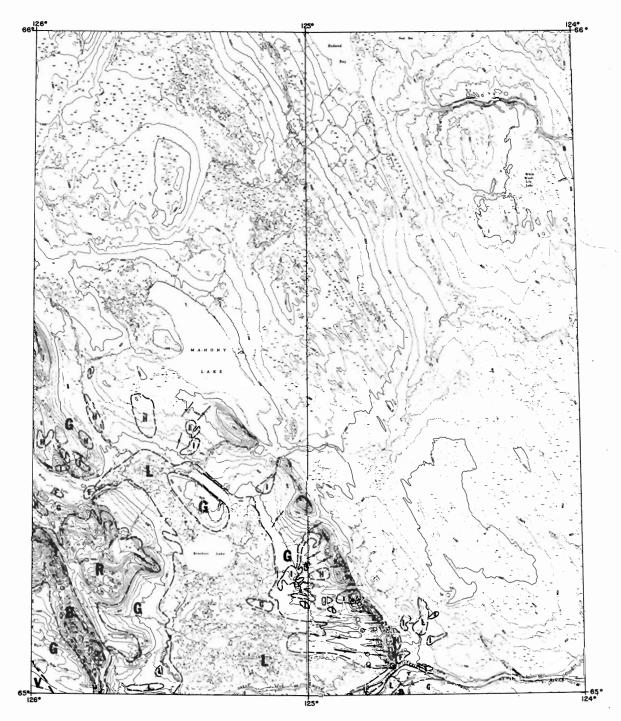
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- VILINGES AND SOME INDUSTRIES OF HIGHLY VARIABLE QUALITY GROUND MATER Cenerally springs occur in loviand areas along valley banks where permeable soil or rock materials overlie impermeable sirata. The springs may be artestan or vater-table. Potentially suitable for towns, industries, and construction campaites depending on war-er quality.
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- PROPER INTAKES INTO LARGE LAKES MAY YIELD UP TO 100 IGPM OF GOOD QUALITY WATER; DEPTH OF WATER (PREFERABLY OVER 10 FEET) AND SIZE OF LAKE ARE IMPORTANT CONSIDERATIONS, THE LARGER AND DEEPER LAKES BEING BETTER Consists of larger and deeper personent lakes in Mackenzie River Valley upland, such as Tess and Stewart Lakes. Potentially fair to good water supplies for villages, industries, and construction camps. Treatment for Iron, mangaese, and organic matter may be necessary. Because of potentially thick (see cover on smaller shallow lakes, the availability of this water source may vary seasonally.



MAHONY LAKE

SURFICIAL HYDROGEOLOGY MAP RECONNAISSANCE

GENERALIZED HYDROGEOLOGY MAP OF SURFICIAL DEPOSITS
SHOWING GROUND-WATER PROBABILITY ALONG MACKENZIE RIVER VALLEY
FORT SIMPSON TO FORT APPEARSON, NORTHWEST TERRITORIES

(Note: Estimate of yield are probable, not absolute, maximum figures, which also exclude possible buried bedrock valleys partly 'hand with granular strata but having no surface expression)

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 in major river walleys cributary to the Machenie River. Consider
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 Considerable test drilling my be required to locate large aquifers
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 lateral and vertical river erosion. Rivers with headwaters in the
 Mackenzie Mountains are extremely flashy and floods can be highly
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- O.T. PROPERLY LOCATED, DEVELOPED AND CONSTRUCTED INDIVIDUAL WATER WELLS
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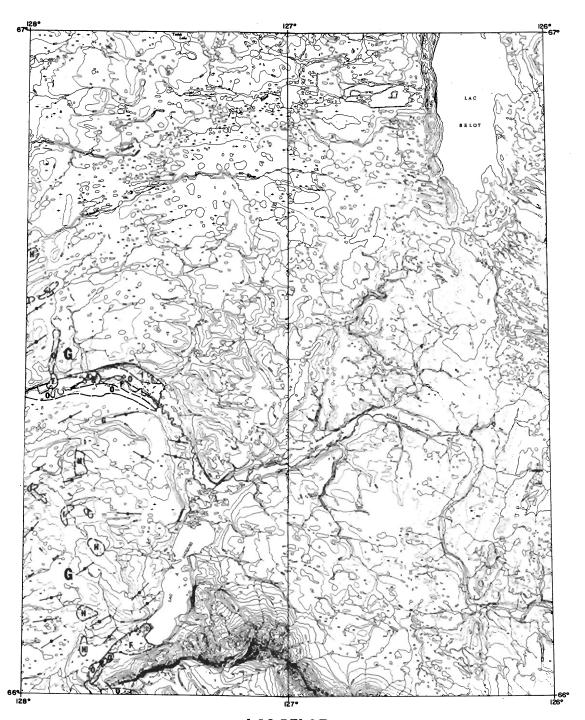
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Map 14



LAC BELOT

RECONNAISSANCE SURFICIAL HYDROGEOLOGY MAP

GENERALIZED HYDROGEOLOGY MAP OF SURFICIAL DEPOSITS
SHOWING GROUND-WATER PROBABILITY ALONG MACOUNTY RIVER VALLEY
FORT SIMPSON TO FORT MCF. LEGG., DOKEMENT TERRITORIES

(Note: Estimates of yield are probable, not absolute, maximum figures, which also exclude possible buried bedrock valleys partly filled with granular strata but having no surface expression)

LEGEND

Explanation

- PROPERLY LOCATED, DEVELOPED AND CONSTRUCTED INDIVIDUAL WATER UPILS

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 W. MATER, ARE PREQUENTLY PLOODED, OR ARE SITUATED ON SOUTH-FACING EXPOuse. Detailed airphoto study coupled with thorough field geological
 reconnaissance is needed to pinpoint preferred testhole-exploration
 sites. Expect limited ground-water recharge. Ground water will likely require some treatment, such as removal of iron and manganese.
 The more promising well sites are commonly restricted to places on
 active distributaries and abendoned channels on larger alluvial and
 colluvial fans marked A and C, the margins of larger ponds and creekbeds in areas marked E and D, and south-facing slopes on higher largerevoced ridges marked W and I in regional low-land areas receiving
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- L VINDIVIDIDAL WELLS ARE EXPECTED TO YIELD LESS TRAN 1 ICPM OF POOR ICALLY WATER Generally poor ground-water serice for all prospective vater users because of low permeditive, low recharge perceive vater users because of low permeditive, low recharge in the large of the prospective prospective
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SURFICIAL HYDROGEOLOGY MAP RECONNAISSANCE

GENERALIZED HYDROGEOLOGY MAY OF SUBJICIAL MODSITIS
VING GROUND-WATER PROBABILITY ALONG MACONELE BIVER VALLEY
FORT SIMPSON TO FORT MEPHERSON, RUKTHWEST TERRITORIES SHOWING GE

(Note: Estimates of yield are probable, not absolute, maximum figures, which also exclude possible buried bedrock waiteys partly filled with granular strata but having no surface expression)

Symbol

Explanation

- F PROPERLY LOCATED, DEVELOPED AND CONSTRUCTED INDIVIDUAL WATER WELLS
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- O,T PROPERTY LOCATED, DEVELOPED AND CONSTRUCTED INDIVIDUAL WATER WELLS
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race deposits containing minor gravelly and silt interbeds

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The more promising well sites are commonly restricted to places on
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- B,R,K YILLDE FROM PROFESCY COCKEE, DEVELOPED AND CONSTRUCTED INDIVIDUAL WATER WELLS ARE CONCISED TO WATER FROM LESS THAN 1 IGPM IN THICK SHALE SEQUENCES TO POSSIBLY 250 IGPM AT SELECT LOCATIONS IN HIGHLY

- DISTURBED AND FRACTURED NON-MARINE SANDSTONE AND PORCES CARROMATE ROCKS AND IN MICE UNCOMPRED PERTIARY EASY AND EAVEL (SET, ALSO, THE ACCOMPANYS CREMEATINE BREMON MYRESOCCION AND Bighly variable ground-water source, both from the standpoints of voter quality and quantity. Potentially suitable for domestic supplies, villages and some industries in certain localities.
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 Where permetals soil or rock materials overies impermeable strata.

 The springs may be artesian or vater-table. Potentially suitable

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ONTARATUE RIVER

RECONNAISSANCE SURFICIAL HYDROGEOLOGY MAP

(Note: Estimatem of yield are probable, not absolute, maximum figures, which also exclude possible buried bedrock valleys partly filled with granular strata but having no surface expression)

Explanation

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- O,T PROPERTY LOCATED, DEVELOPED AND CONSTRUCTED INDIVIDUAL MATER VELLS MAY YIELD UP TO 25 1670 OF GOOD QUALITY MATER WHERE THESE CHANULAR SERVEDTE ARE UNFORCED AND CONTINUENT MERCHANTED RETURN PROPERTY OCCUR SOUTH OF MORROW WELLS, ESPECIALLY TELOCATE MAY LIKE SECTIONS OF SAME AND GRAVEL COVERED BY LACATINE, WHITE SPHUER, BAILSAN POPLAR, AND TALL WILLOWS Potentially fair to good possibilities for tourist camps, domestic use (washing, drinking) at construction camps, and small native-settlements. Consists mainly of sandy outwash and ter-

race deposits containing minor graveIly and silt interbeds.

race deposits containing minor gravelly and sile interbeds.

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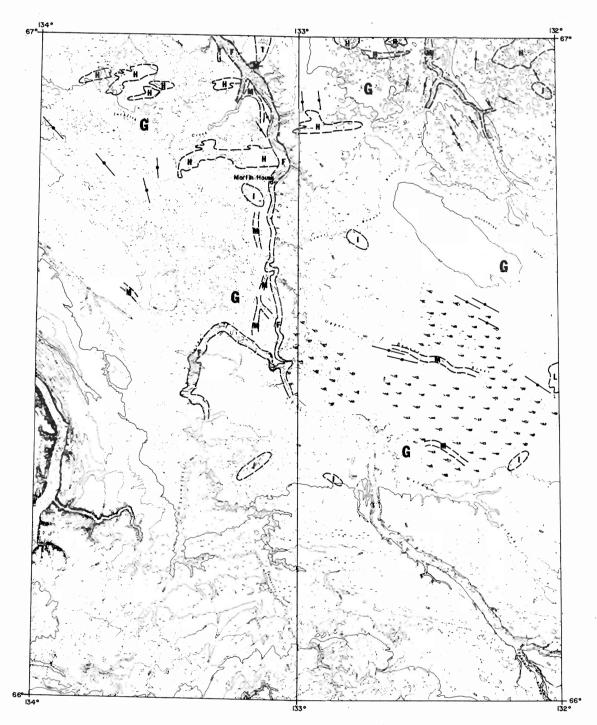
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- Valuages and some industries in certain localities.

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MARTIN HOUSE

SURFICIAL HYDROGEOLOGY MAP RECONNAISSANCE

GENERALIZED HYDROGEOLOGY MAP OF SURFICIAL DEPOSITS
SHOWING GROUND-WATER PROBABILITY ALONG PACKETE RIVER VALLEY
FORT SIMPSON TO FORT M-PHERSON, MORTHWEST TERRITORIS

(Note: Estimates of yield are probable, not absolute, maximum figures, which also exclude possible buried befreck valleys partly filled with granular strata but having no surface expression)

LEGEND

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 FROPERLY LOCATED, DEVELOPED AND CONSTRUCTED INDIVIDUAL WATER WELLS

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 Considerable test drilling may be required to locate large aquifers
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 plain. Chief well installation problems are flooding and expension
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 Mackenie Rountains are extremely flashy and floods can be highly
 destructive.

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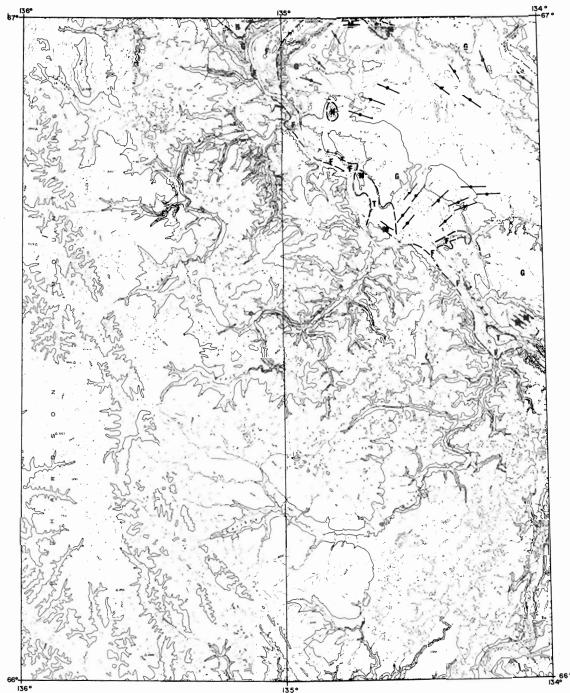
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- B,R,K YIELDS FROM PROPERTY LOCATED, DEVELOPED AND CONSTRUCTED INDIVIDUAL MATER WELLS ARE EXPECTED TO VARY FROM LESS PLANT I: GPM IN THICK SHALE SEQUENCES TO PRESENTE 250 LOPP AT SELECT LOCATIONS IN RIGHLY

- DISTURBED AND FRACTURED BON-MARINE EARSTONE AND FORDUS CARBORATE ROOKS AND IN THICK UNCOMMENTED TENTIANT SAND AND GRAVEL (EEK, MISO, THE ACCOPANTION CEREALIZED BEDGOCK PROPROGROUDED HAP) Highly risk by ground-water source, both from the standpoints of water quality and quantity. Potentially suddamle for domestic supplies, villages and some industries in certain localities.
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 Map 18



TRAIL RIVER

SURFICIAL HYDROGEOLOGY MAP RECONNAISSANCE

CONTRACTZED HYDROGEOLOGY MAP OF SHEPTCIAL DEPOSITS
SHOWING CHOUND-WATER PROBABILITY ALONG MACCOZIZE RIVER VALLEY
FOUT THAPSON TO FORT MAPHERSON, NORTHWAST TERRITORIES

(Note: intimates of yield are probable, not absolute, maximum figures, which also exclude possible buried bedrock valleys proving fixing with granular strata but having no surface expression)

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race deposits containing minor gravelly and silt interbeds.

race deposits containing minor gravelly and silt interbeds.

A. PROPERLY LOCATED, DEVELOPED AND CONSTRUCTED INDIVIDUAL WATER WELLS

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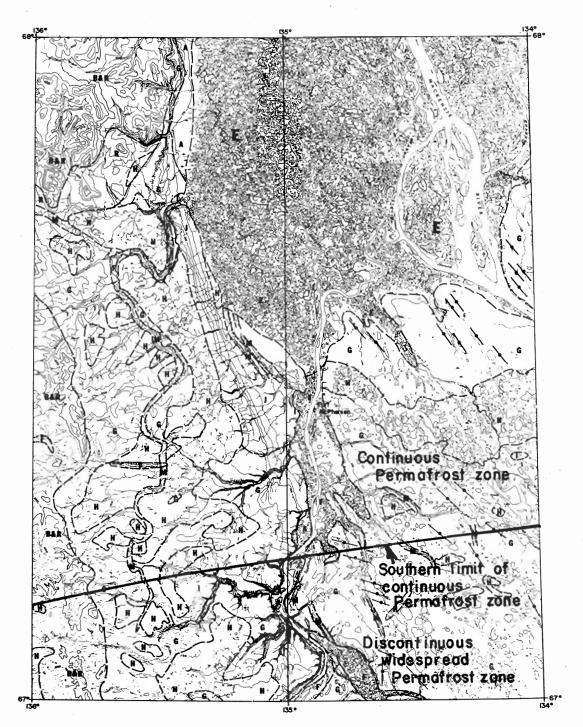
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FORT McPHERSON

RECONNAISSANCE, SURFICIAL HYDROGEOLOGY MAP

(Note: Estimates of yield are probable, not absolute, maximum figures, which also exclude possible buried bedrock walleys partly filled with granular strata but having no surface expression)

LEGEND

Symbol

Explanation

- Explanation

 PROPERLY LOCATED, DEVELOPED AND CONSTRUCTED INDIVIDUAL WATER WELLS
 MAY YIELD UP TO 50 TO 100 IGPM AND LOCALLY, IN THICKER HORE PERMEABLE AQUIFERS, 100 TO 500 IGPM OF GOOD QUALITY WATER Forentially
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 and towns, and industries especially those thick coarse aquifers
 in major river valleys tributary to the Mackenzie River. Consists
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 Considerable test drilling may be required to locate large aquifers
 in the lower reaches of tributaries and in the Mackenzie River flood
 plain. Chief well installation problems are flooding and excess
 lateral and vertical river erosion. Rivers with headwaters in the
 Mackenzie Mountains are extremely flashy and flood can be highly
 destructive.

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race deposits constaining minor gravelly and silt interbeda.

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revooled ridges marked W and I in regional lowland areas receiving
recharge.

L VINDIVIDUAL WELLS ARE EXPECTED TO YIELD LESS THAN 1 IGPM OF POOR H. QUALITY WATER Generally poor ground-water sources for all prospective water users because of low permeability, low recharge N. J. posstbilities, and a high permafrost table. Recharge is limited M. As to larger themokarst features — mainly in map-units b. and H. Expect sulphate waters having potentially high iron and manganese contents. Consists mainly of firm-grained, low-permeability lacustrine and till deposits, the latter containing minor and randoml occurring inclusions of sand and, less commonly, gravel. Expect subsoils to be widely frozen (permafrest).

B,R,K YIELDS FROM PROPERLY LOCATED, DEVELOPED AND CONSTRUCTED INDIVIDUAL MATER WELLS ARE EXPECTED TO WARY FROM LESS FIRM I LOTM IN THICK SHALE SEQUENCES TO POSSIBLY 250 LOPM AT SELECT LOCATIONS IN HIGHLY

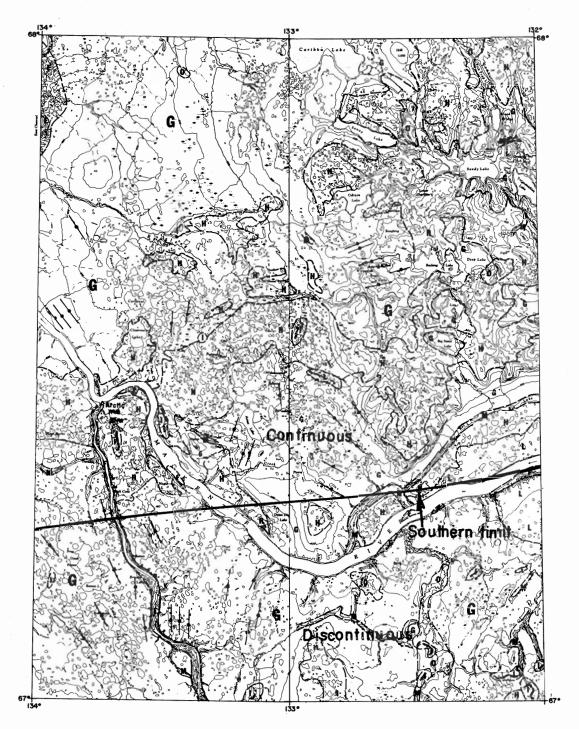
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Map 200



ARCTIC RED RIVER

RECONNAISSANCE SURFICIAL HYDROGEOLOGY MAP

GENERALIZED HYDROGEOLOGY MAP OF SURFICIAL DEPOSITS
WING GROUND-WATER PROBABILITY ALONG MACCINETE RIVER VALLEY
FORT SIMPSON TO FORT MCPHERSON, NORTHWEST TERRITORIES

(Note: Estimates of yield are probable, not absolute, maximum figures, which also exclude possible buried bedrock valleys partly filled with granular strata but having no surface expression)

LEGEND

Explanation

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- race deposits containing minor gravelly and silt interbeds.

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- DISTURBED AND FRACTURED NON-MARINE SAMPAGEMENT AND PORGUS COMMANDER ROCKS AND IN THICK IN COMPATED TERTIARY SAMP AND GRAVEL (SEE ALSO, THE ACCOMPANING GENERALIZE BROCKS THROCKCOMPANING CHE PALLIZE BROCKS THROCKCOMPANING CHECK TO ALLIZE BROCKS THROCKCOMPANING CHECK THROCK THR
- VILIAGES and some industries in certain localities.

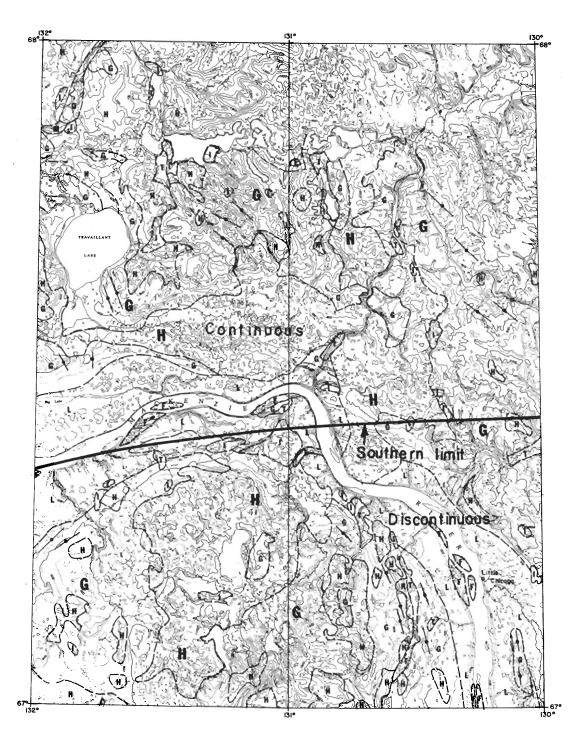
 SPRINGS VIELING LARGE QUANTITIES OF HIGHLY VARIABLE QUALITY GROUND

 WATER Community springs occur in lowland areas along valley banks
 where permeable soil or rock materials overlie impermeable strata.
 The springs may be artestan or vater-table. Fotentially suitable
 for towns, industries, and construction campaites depending on vater quality.
- er quality.

 INDIVIDUAL WELLS IN ORGANIC (PEAT) DEFOSITS ARE EXPECTED TO YIELD LESS THAN 1 IGPN OF FOOR QUALITY W/TER Generally poer vater supplies for all users because of the typical ten colour of the vater, potentially high amagenese and from contents and common boxyy factic and odour. Includes fens, bogs, marshely. End Symaps. Generally patterned fens are unfromen in vicinity of fort Simpson wiererally patterned ends are unfromed. The vicinity of fort Simpson wiererally patterned and the maall, roundish, treeless collapse scars in peat plateand are unfrommen.
- Like PROTE INTAKES INTO LARGE LAKES MAY YIELD UP TO 100 IGPM OF GOOD QUALITY WATER; DEPTH OF WATER (PREVENEUR NUMBERS OF COLE OF LAKE ARE IMPORTANT CONSIDERATIONS, THE LAKES AND ENTRE LAKES BLOOK FOR THE RESEARCH OF THE RESEARCH OF THE RESEARCH OF THE RESEARCH STATE OF THE RESEARCH OF THE RESEARCH REVER VAILE; Upland, such as Tate and Stewart Lakes. Potentially fair to good "state supplies for villages, industries, and construction" comp.

 Treatment for ton, managemen, and organic matter may be necessary. Because of potentially thick ice cover on smaller shallow lakes, the availability of this water source may vary seasonally.

 Map 21 Map 21



TRAVAILLANT LAKE

RECONNAISSANCE SURFICIAL HYDROGEOLOGY MAP

GENERALIZED HYDROGEOLOGY MAP OF SURFICIAL DEPOSITS
SHOWING GOUND-WATER PROBABILITY ALONG MACKENZIE RIVER VALLEY
FORT SIMPSON TO FORT McPHERSON, NORTHWEST TERRITORIES

(Note: Estimates of yield are probable, not absolute, maximum figures, which also exclude possible buried bedrock valleys partly filled with granular strata but having no surface expression)

Explanation

- PROPERLY LOCATED, DEVELOPED AND CONSTRUCTED INDIVIDUAL WATER WELLS
 MAY YILD UP TO 50 TO 100 IGPH AND LOCALLY, IN THICKER WORE PERREMAY YILD UP TO 50 TO 100 IGPH AND LOCALLY, IN THICKER WORE PERRESOLE ADULTES, JOO TO 500 IGPH OF GOOD COMAINTY ATER
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 good water supplies for couriet and commitment of comps, will sale
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 good the comps, will sale
 and incommitment of the Mackensie River. Consiste
 mainly of alluvial sand and gravel below the active and wooded (inactive) floodplains and below coarse sandy and gravelly point-bar
 deposits on sceeper-gradent sections of larger meandering rivers.
 Considerable test drilling may be required to locate large aquifers
 in the lower reaches of tributaries and in the Mackensie River flood
 plain. Chief well installation problems are flooding and **commitment of the commitment of the commitmen
- O, T PROPERTY LOCATED, DEVELOPED AND CONSTRUCTED INDIVIDUAL WATER VELLS

 NAY YILLS UP TO 25 ICPM OF GOOD QUALITY WATER WHERE THESE CANALAR
 SEDIMENT ARE UNFROOR AND CONTINUALLY RECURSORD SETTER FORST CTS
 OCCUR SOUTH OF NORMAN WELLS, ESPECIALLY THICKER LOW-LYING SECTIONS
 OF SAND AND GRAVEL COVERED WIJ ACCURACY, MILES SPRUCE, BALSAN FORLAS,
 AND TALL WILLOWS FORENTIALLY fair to good possibilities for tourist
 camps, domestic use (washing, atching) at construction camps, and
 small native settlements. Commission with you wash and ter-

race deposits containing minor gravelly and silt interbeds.

- race deposits containing minor gravelly and sitt interbeds.

 A.C. PROPERLY LOCATED, DEVELOPED AND CONSTRUCTED INDIVIDUAL WATER WELLS

 E.D. HAY YIELD UP TO 5 IGHO FOROR TO FAIR QUALITY WATER, BETTER PROSPROCTS (COMPONIN MAP-UNITS A AND I) OCCUR IN LOCALITIES THAT BORDER

 W. LATER, ARE PREQUENTLY PLOODED, OR ARE SITUATED ON SOUTH-PACKING EXPOSWALL Generally poor to locally fair water supplies for domestic

 www. Detailed airphot study coupled with thorough field geological

 Freenmaissance is needed to pinpoint preferred teathole-exploration

 sites. Expect limited ground-water recharge. Cround water vill likely require some treatment, such as removal of from and managanese.

 The more promising well sites are commonly restricted to places on

 active distributaries and abandomed channels on larger alluvial and

 colluvial fans marked A and C, the margins of larger ponds and creek
 beds in areas marked E and D, and south-facing slopes on higher larg
 er vooded ridges marked W and I in regional lowland areas receiving

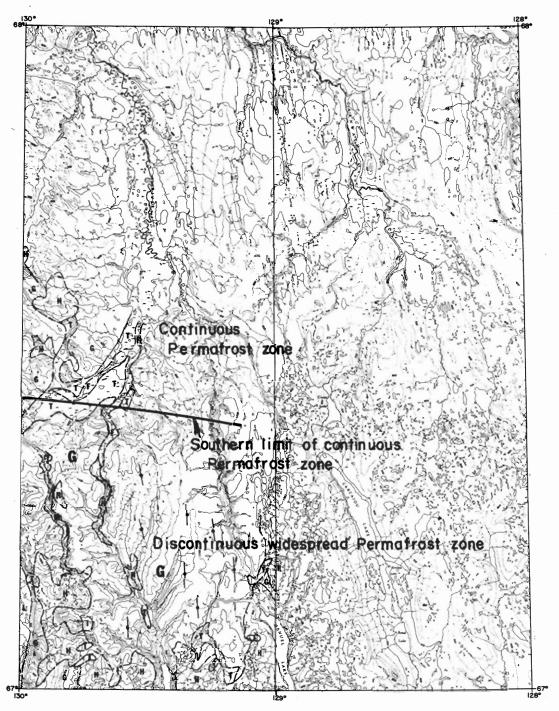
 recharge.
- LY INDIVIDAL WELLS ARE EXPECTED TO YIELD LESS THAN 1 TOPM OF POOR IN GOULDITY WATER Generally poor ground-water sources for all prosports. The poor the water wears because of low permedulity, low recharge N, J possibilities, and a high permafrost table. Secharge is limited M, AS to larger thermokarst features mathly in map-units L and H. Expect sulphate veters having potentially high from and manganese contents. Consider mainly of fine-grained, low-permedulity lacustrine and till deposits, the latter containing minor and randomly occurring inclusions of sand and, less commonly, gravel. Expect subsoils to be widely frozen (permafront).
- B,R, M YIELDS FROM PROPERLY LOCATED, DEVELOPED AND CONSTRUCTED INDIVIDUAL WATER WELLS ARE EXPECTED TO VANY FROM LESS THAN 1 IGPM IN THICK SHALE SEQUENCES TO POSSIBLY 250 IGPM AT SELECT LOCATIONS IN HIGHLY

DISTURBED AND FRACTURED NON-MARINE SANDSTONE AND POROUS CARBONATE ROCKS AND IN THICK UNCHEMPED TERTLARY SAND AND GRAVEL (SEE, ALSO, THE ACCOPPANYING CENTRALIZED BEBROCK HYPROCOLOGY MAP) Highly variable ground-water source, both from the standpoints of water quality and quantity. Potentially suitable for domestic supplies, villages and some industries in certain legalities.

- ***Lingues and some industries in certain legalities.

 SPRINGS YIELDING LARGE QUANTITIES OF MIGHIY VARIABLE QUALITY GROUND
 MATER Generally springs occur in local and areas along walley banks
 where permeable soil or rock materials overlie impermeable strata.
 The aprings may be artesian or vater-table. Forenti-lly suitable
 for come, industries, and construction campaites depending on vater
 quality.
- THENTIDIAL WELLS IN ORGANIC (PEAT) DEPOSITS ARE EXPECTED TO YIELD LISS THAN 1 IGPN OF POOR QUALITY WATER Generally poor water supplies for all users because of the typical tac colour of the water, potentially high manganese and iron contents and common boggy taste and odour. Includes fens, boggs, marshes, and swamps. Generally patterned fens are unfrozen in vicinity of Fort Simpson whereas only the manganese collapse scars in peat plateaus are unfrozen.
- PROPER INTAKES INTO LATE LOUIS MAY VIELD UP TO 100 IGPH OF GOOD QUALITY WATER; DEPTH OF MATER (PATTERLEY OUR 10 FEET) AND SIZE OF LAKE ARE REPORTANT CONSIDERATIONS, THE LAGIE AND HETER LAKES BEING BETTER Consists of larger and deeper permenent laws: In Mackenzie River Valley upland, such as Tate and Stewart Lakes. Potentially fair to good water supplies for villages, industries, and construction camps. Treatment for Iron, manganese, and organic matter may be necessary. Because of potentially thick ice cover on smaller shallow lakes, the availability of this water source may vary seasonally.

 MOD 22



CANOT LAKE

SURFICIAL HYDROGEOLOGY MAP RECONNAISSANCE

GENERALIZED HYDROGEOLOGY MAP OF SURFICIAL DEPOSITS
SHOWING GROUND-WATER PROBABILITY LONG MACCONZIE RIVER VALLEY
FORT SIMPSON TO FORT MCPHERSON, MORTHWEST TERRITORIES

(Note: Estimates of yield are probable, not absolute, maximum figures, which also exclude pessible buried bedruck valleys partly filled with granular strata but having no aurface expression)

LEGEND

Explanation

- Explanation

 Explanation

 PROPERLY LOCATED, DEVELOPED AND CONSTRUCTED INDIVIDUAL WATER WELLS

 MAY YIELD UP TO 50 TO 100 IGPM AND LOCALLY, IN THICKER MORE REDWING

 ABLE AQUITERS, 100 TO 500 IGPM GOOD QUALITY WATER PORTILIATIVE
 good water supplies for tourist and construction camps, villiges
 and towns, and industries especially those thick coarse aquifers
 in major river valleys tributary to the Mackenzie River. Consists

 matinly of alluvial sand and gravel below the active and wooded (in
 active) floodplains and below coarse sandy and gravelly point-bar

 deposits on steeper-gradient sections of larger meandering rivers.

 Considerable test drilling may be required to locate large aquifers
 in the lower reaches of tributaries and in the Mackenzie Miver flood

 plain. Chief well installation problems are flooding and excessive

 lateral and vertical river erosion. Rivers with headwaters in the

 Mackenzie Mountains are extremely flashy and floods cam be highly

 destructive.

 **PROPERLY LOCATED, DEVELOPED AND CONSTRUCTED INDIVIDUAL WATER WELLS
- O.T PROPERLY LOCATED, DEVELOPED AND CONSTRUCTED INDIVIDUAL WATER WELLS
 MAY YIELD UP TO 25 IGPM OF GOOD QUALITY SATES WHERE THESE GRANULAR
 SEDIMENTS ARE UNPROCED AND CONTINUALLY RECURSION. BETTER PROSPECTS
 OCCUR SOUTH OF NORMAN WELLS, ESPECIALLY THICKER LOM-LYING SECTIONS
 OF SAND AND GRAVEL COVERED BY JACKPINE, WHITE SPRUCE, BAISAN POPLAR,
 AND TALL WILLOWS Potentially fair to good possibilities for tourist
 camps, domestic use (Mashing, strains) at contraction camps, and
 small marker settlements. Commists mainly of sandy outwash and ter-

race deposits containing minor gravelly and silt interbeds.

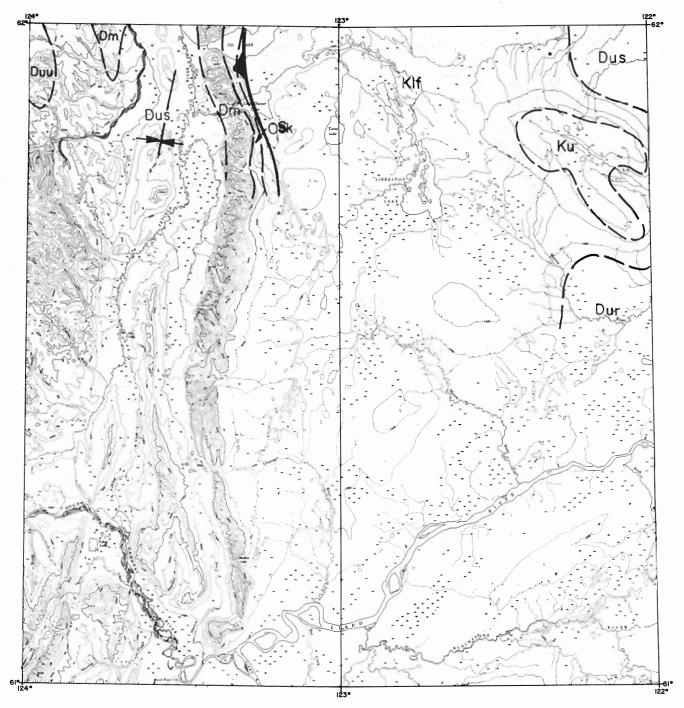
- Tace deposits containing minor gravelly and silt interbeds.

 A.C. PROPERLY LOCATED, ENVILOYED AND CRESTRUCTED INDIVIDUAL MATER WELLS
 E.D. MAY HILLD WE TO 5 LOFE OF FOCK TO FAIR QUALITY WATER, BETTER PROSPROPERLY CONTROL NOT SO AND SY DUCKIN INCOLUTIES THAT BOXER
 WATER, AGE FROQUENTY FLOODED, OR ARE SITUATED ON SOUTH-FACINETY
 SURES Generally poor to locally find with thospight field geological
 reconstance is needed to pippoint preferred teethule-exploration
 sites. Expect limited ground-water recharge. Ground water will likely require some treatment, such as removal of iron and mangane.
 The more promising well sites are commonly restricted to places on
 active distributaries and shandoned channels on larger alluvial and
 colluvial fans marked A and C, the margins of larger ponds and creekbeds in areas marked E and D, and south-facing slopes on higher larger wooded ridges marked W and I in regional lowland areas receiving
 recharge.
- L VINDIVIDAL WELLS ARE EXPECTED TO YIELD LESS THAN 1 16PM OF POOR H, QUALITY WATER Generally poor ground-water sources for all prosping processing the processing of the processing of the processing of the processing of the possibilities, and a high permafront table. Recharge is limited M.AS to larger thermokarst features madnly in map-units L and H. Expect submission waters having potentially high from and manganese contests. Commission mainly of theory than the processing of the processing including of the stable of the processing including of the stable of the processing of the processing including of the stable of the processing of the processing
- B,R,K YIELDS TON PROPERTY LOCATIED, DEVELOPED AND CONSTRUCTED INDIVIDUAL WATER WILLS AND EXPECTED TO VARY FROM LESS THAN 1 IGPM IN THICK SHALE SEQUENCES IN PROSIBLY 250 IGPM AT SELECT LOCATIONS IN HIGHLY

DISTURBED AND FRACTURED NON-Mains: SANDSTONE AND POROUS CARBONATE ROCKS AND IN THICK UNCHENTED TERTILARY SAND AND GRAVEL (SEE, ALSO, THE ACCOMPANING GENERALIZED Lange, KR MPROGEOLOGY May Highly variable ground-water source, both from the standpoints of water quality and quantity. Potentially suitable for domestic supplies, villages and some industries in certain localities.

- S SPRINGS TRELIDING LARGE QUANTITIES OF HIGHLY VARIABLE QUALITY GROUND WATER Generally springs occur in lowland areas along valley banks where permeable sof; or rock materials overliet impermeable scatch. The springs may be artesian or water-table. Potentially suitable for towns, industries, and construction campsites depending on water quality.
- INDIVIDUAL WELLS IN ORGANIC (PEAT) DEPOSITS ARE EXPECTED TO YIELD LESS THAN 1 1GPM OF POOR QUALITY WATER Generally poor water supplies for sil users because of the typical tes colour of the water, potentially high amaganese and from contents sed common bogy taste and odour. Includes fens, bogs, marshes, and swamps. Cenerally patterned fens are unfrozen for vicinity of Fort Simpson whereas only the small, roundish, treeless collapse scars in peat plateaus are unfrozen.
- Zen.

 Lake PROPRE INTAKES INTO LARGE LAKES MAY YIELD UP TO 100 IGPM OF GOOD QUALITY WATER; DEPTH OF WATER (PREFERALY OVER 10 FEET) AND SIZE OF LAKE ARE INFOCENATIONS; THE LARGE AND DEEPER LAKES BEING BETTER Consists of Large and sever permanent lakes in Mackendie River Valley upland, such a Tate and Scavart Lakes. Potentially fair to good water supplies for villages, industries, and construction campations of the consist o



SIBBESTON LAKE

RECONNAISSANCE BEDROCK HYDROGEOLOGY MAP

LEXEND OF GENERALIZED BEDROCK HYDROGOLOGY MAP
SHOWING CROCKE-WATER PROBABILITY ALONG PRODUCTE RIVER VALLEY
FORT SINGSON TO FORT MCPHERSON, NORTH-EST ILLUSTRIES

(Note: The entire study-area is underlain by widespread permafrost in the discontinuous permafrost zone; also, estimates of yields refer to probable, not absolute, maximum figures and to generally more highly disturbed, fractured, and porous zones within the formations)

Symbol [] Explanation

- Tertiary non-marine sand, gravel, conflowerate, shale, sandstone, coal. Expect maximum yields of 30 Igym of generally fair to good quality waters
- Upper Cretaceous mainly non-marine sandstone and shale. Expect maximum yields of 25 Igpm of generally poor to locally fair quality
- Lower Cretaceous mainly marine shale and samistone. Expect maximum yields of 1 Igpm of poor quality sulphate waters
- Upper Cretaceous Fort St. John Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
- Upper and Lower Cretaceous winamed and undivided mainly marine sha-le and sandstone. Expect maximum yields of 5 Igpm of generally poor quality waters
- poor quality waters (Pennsylvani.m) and Permian unramed and undivided sand-stone and complementate. Expect maximum yields of 25 Igpm of poor to locally fair quality waters
- Upper Devonian Redknife Furnation mainly marine smale with minot sandstone and linestone. Expect maximum yields of 1 igps of generally poor quality waters

- لصصة Upper Devonian unmamed mainly mon-marine shale, siltstone, limestone, and sandstone. Expect maximum yields of 5 Igpm generally poor to locally fair quality waters
- Upper Devoni m layerial Fermation mainly non-marine shale and sand-stone. Expect maximum yields of 5 Igpm of generally poor to locally fair quality vaters
- Upper Devonian Kakisa Formation limestone. Expect maximum yields of 5 ligms of poor to locally fair quality bidarbonate waters
 Upper Devonian Trout River and Tercho Pormations commissing mainly of limestone with minur shale and mandatone. Expect maximum yields of 3 ligms of poor to locally fair quality generally bicarbonate waters
- Upper Devonium Fort Simpson Formation marine shale and siltstone. Expect maximum yields of less than I Igpm of generally poor quality sulphate waters
- Middle Devenian unnamed and undivided mainly carbonate strata with minor shale and anhydrite. Expect maximum yields of 250 Igpm of variable quality bicarbonate-sulphate waters
- Middle Devemian Kee Scarp Formation reefal and other limestones. Expect maximum yields of 100 Igps of poor to locally fair quality generally bicarbonate, hard waters
- Middle Devomies Kee Scarp Formation limestone and Hare Indian cal-carecies shale. Expect maximum yields of 25 Igpm of variable qual-ity generally bicarbonate, hard waters Tectonic symbols: - thrust fault with teeth indicating direction of dip; - anticline;

- Middle Devonian Hume Formation libertune. Expect maximum yields of 10 Igpm of variable quality generally bicarbonate, hard waters
- Middle Devonian Canol Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
- Middle Devonian Canol and Mars Indian Formations commisting mainly of shale. Expect maximum yields of 1 Igpm of poor quality bicarb-onate-sulphate waters

- onate-sulphate vaters

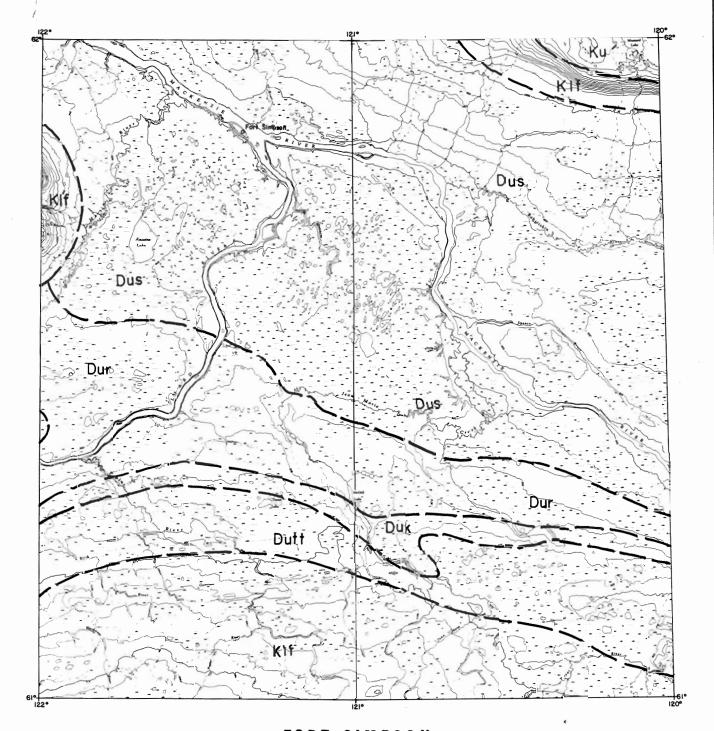
 Middle Devosian Bear Rock Formation dolonite, limestone, and anhydrite. Expect maximum yields of 250 Igm of very poor quality generally bicarbomate-sulphate vaters.

 Middle Devosian Hare Indian Formation shale. Expect maximum yields of 1 Igm of poor quality sulphate vaters.

 Ordovician and Silurian unmaned and undivided dolonite and limestmentally bicarbomate-milphate vaters.

 Ordovician and Silurian hour; Kindle Formation dolonite and anhydrate and Formation Mour; Kindle Formation dolonite and shale. Expect maximum yields of 10 Igm of generally port to locally fair quality bicarbomate-wilphate vaters.
 - constraintion and the representation analysis grown and salt, Cap Mt. Combrian Saline River Formation analysis and salt, Cap Mt. Formation shalt and Mt. Clark Formation sandatome. Expect maximum yields of 100 kpm of poor quality subject and love a waters from the Saline River salt and anhydrite, 1 kpm of poor quality sulphate vaters from the Cap Mt. Formation shale, and 25 kpm of fair quality waters from the Mt. Clark Formation somations
- Precambrian argillite, quartzite, and dolomite. Expect maxis yields of 25 1gps of poor to fair quality waters

Mapl - syncline



FORT SIMPSON

RECONNAISSANCE BEDROCK HYDROGEOLOGY MAP

LECENAL OR GENERALIZED MEDBOCK HYDROGEOLOGY MAP SHOWING CHOOND-WATER PROBABILITY JOHN MACKENZIE RIVER VALLEY FORT SIMPSON TO FORT MAPHENSON, NORTHWEST TERRITORIES

(Note: The entire study-area is underlain, by withouted present fost in the discontinuous permafront most; also, estimates of yields refer to probable, not absolute, maximum figures and to generally more highly disturbed, fractured, and porous zones within the formations)

Symbol Explanation

- Tertiary non-marine sand, gravel, congligmerate, shale, sandstone, coal. Expect maximum yields of 50 Igps: of gherally fair to good quality waters
- Upper Cretaceous mainly non-marine sandstone and shale. E: geet maximum yields of 25 Igpm of generally poor to locally fail quality
- Lower Cretaceous mainly marine shale and sandstone. Expect maximum yields of 1 Igpm of poor quality sulphate waters
- Upper Cretaceous Fort St. John Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters KIf
- Upper and Lower Cretaceous unnamed and undivide 8 mainly marine hale and sandstone. Expect maximum yields of 5 I gpm of generally poor quality waters
- Carboniferous (Pennsylvanian) and Permian unnamed and undivided sand-stone and conglowerate. Expect maximum yields of 25 Igpm of por to locally fair quality waters
- Upper Devomian Redknife Formation mainly marine shale with minor sands:tone and limestone. Expect maximum yields of 1 Igpm of generally poor quality waters

Tectonic symbols:

- Upper Devonian unnamed mainly non-marking shale, siltstone, limestone, and samistone. Expect maximum yield: of 5 Igpm generally poor to locally fair quality waters
- Upper Devonian Imperial Formation mainly non-marine shale and sand-stone. Expect maximum yields of 5 Igpm of generally poor to locally fair quality waters
- Upper Devonian Kakis; Formatin limestone. Expect maximum yields of 5 Igom of poor to locially fai quality bicarborate waters

 Doper Devonian Trout River and Tetcho Formations Consisting Mainly
 of limestone with minter shake and sandatone. Expect maximum yield
 of 5 Igom of poor to locally fair quality generally bicarlocomate
 waters
- Upper Devonian Fort Simpson Formation marked and siltstolm. Expect maximum yields of less than 1 I gpm of generally poor quality sulplate waters
- Middle Devonian unnamed and undivided mainly tarbonic strata with minor shale and anhyforite. Expect makimum yi elds on 250 Igpm of variable quality bicarbonate-sulphats waters
- Middle Devonian Kee Scarp formation meefal and other limestones.

 Expert. maximum.yiel. is of 100 Iggm of poor to locally fair quality generally bicabonate, hard waters
- Mid-file Devomies Kee Scieny Tormstion Monocone work tone Coding cal-car four shale. Expect maximum yields of 25 Igum of variable qual-ity generally Micarbon ate, hard waters
- thrust fault with teeth in dicating direction of dip; anticline;

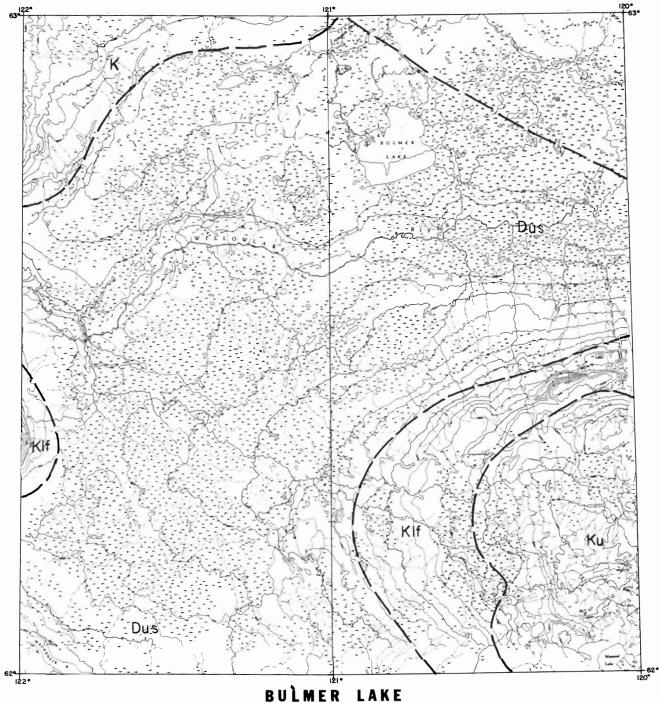
- Middle Devonian Hume Formation limestone. Expect maximum yield; of 10 Igpm of variable quality generally bicar bonate, hard vaters Dmh

- O igmo of variable quality generally bicar bears, hard vasues of 10 igmo of variable quality generally bicar bears and vasues of 1 igmo of variable quality generally bicar bears and vasues of 1 igmo of variable quality bicarbenate acres. Niedd is Deventan Canol and Mare Indian Forma one consisting mainly of shake. Expect maximum yields of 1 igmo of poor quality bicarbenate acres. Niedd is Deventan Bear Rock Formation indicate, limestone, and anhydrite. Expect maximum yields of 100 immo vary poor quality generally bicarbenate-sulphate vasters. Expect maximum yields of 1 igmo of poor quality valibate vasters. Ordovician and Silurian unneard and undivided dolomite and limestrally bicarbenate-sulphate vasters. Expect maximum yields of 10 igmo of period of the proof highly variable quality severally bicarbenate-sulphate vasters. Expect maximum yields of 10 igmo of generally peor to leasly fair quality bicarbenate-sulphate vasters.
- onate-sulphate waters
 Cambrian Saline River Formatic membrd; to gypsum and salt, Cap Mt.
 Formation shale and Mt. Clark Formation sandstone. Expect maximum
 yields of water shale and the quality sulphate waters from the
 Saline River salt and ambydris. I law of poor quality sulphate waters from the Cap Mt. Febration shale, see 19 lbm of fair quality
 waters from the Mt. Clark Formation sanie, see 19 lbm of fair quality
 waters from the Mt. Clark Formation sanie, see 19 lbm of fair quality

Precambrian argillite, quartrite, and dislomits. Expect maximum yields of 25 Igpm of poor to fair quality waters

— syncline Map 2

110



RECONNAISSANCE BEDROCK HYDROGEOLOGY MAP

LEGEND OF GENERALIZED SCHOOL STREET HAP SHOWING GROUND-WATER PROBABILITY ALONG MACKETIE RIVER VALLEY FORT SIMPSON TO FORT MCPHESSON, MORTIMEST TERRITORIES

(Note: The entire study-area is undertwin by widespread permafrost in the discontinuous permafrost zone; also, estimates of yields refer to probable, not absolute, maximum figures and to generally more highly disturbed, fractured, and porous zones winin the formations)

Symbol

- Explanation Tertiary non-marine sand, gravel, conglomerate, shale, sandstone, coal. Expect maximum yields of 50 Igpm of generally fair to good quality waters
- Upper Crestaceous mainly non-marine sandstone and shale. Expect maximum yields of 25 Igpm of generally poor to locally fair quality
- Lower Cretaceous mainly marine shale and sandstone. Expect maximum yields of 1 Igpm of poor quality sulphate waters
- Upper Cretaceous Fort St. John Formation shale. Expect maximum yields of 1 Igpm of poor quality sulph ate waters KIF
- Upper and Lower Cretacous unmanded and undivided mainly marine shale and sandstone. Impect maximum yields of 5 Igpm of generally oor quality waters
- Oxfont/ferous (Pennsylvaniam) and Permian unnased and undivided sand-sions and conjugantias. Expect maximum yields of 25 Igpm of poor to locally fair quality waters
- Upper Devonian: Redknife Formation mainly marine shale with minor smaletone and limestone. Expect maximum yields of 1 Igpm of generally poor quality waters

- Upper Devemblan unnamed mainly non-marine shale, siltstone, limestone, and sandstone. Expect maximum yields of 5 Igpm generally poor to locally fair quality waters Dmc
- Upper Devonian Imperial Formation mainly non-marine shale and sand-stone. Expect maximum yields of 5 Igpm of generally poor to locally fair quality waters
- Upper Devonian Kakiss Formation limestone. Expect maximum yields of 5 Igpm of poor to locally fair quality blombonate waters Upper Devominan Trout River and Tetcho Formations committing mainly of limetrogen with minor shale and sandstone. Expect maximum yields of 5 Igpm of poor to locally fair quality generally bicarbonate waters
- Upper Devonian Fort Simpson Formation marine shale and siltstone. Expect maximum yields of less than 1 Igym of generally poor quality sulphate waters .
- Middle Devonian unnamed and undivided mimby carbonate strata with minor shale and subjective. Expect maximum yields of 250 Igpm of variable quality bicarbonate-sulphate vactors. Eiddle Devonian Kee Scarp Formation reefal and other limentomes. Expect maximum yields of 100 Igpm of poor to locally fair quality permeally bicamemate, but camenate waters.
- Middle Devomian Kee Scarp Formation limestone and Hare Indian cal-parament shalle. Expert maximum yields of 25 lgpm of variable qual-ity generally bicarbonate, hard waters

- Middle Devonian Hume Formation limestone, Empect maximum yields of 10 Igpm of wariable anality generally bicarbanate, hard waters

- Disport of variable positive generally bicarbanate, hard waters Middle Dyenian Camel Formation shale. Apparent maximum yields of 1 Igpo of you quality subjate waters Middle Dyenian Camel and Hare Indian Formations consisting mainly of shale. Naport maximum yields of 1 Igpo of poor quality bicarbonate-sulphate waters Middle Devenian Bear Rock Formation dolomite, limestone, and anhydrite. Expect maximum yields of 250 Igpo of very poor quality generally bicarbonate-sulphate waters Middle Devenian Hare being frequention shale. Expect maximum yields of 10 Igpo of poor quality sulphate waters Ordovicing and Silvirie unmaned and undivided dolomite and limestone. Expect maximum index of 10 Igpo of highly variable quality generally bicarbonate-sulphate waters ordovicing and Silvirie winder of 10 Igpo of highly variable quality generally bicarbonate-sulphate waters ordovicing and Silviries winder of the Silviries of Monte Aimelie Formation dolomite and anhydrites and Franklin Far. Formation dolomite and shale. Expect maximum yields of 10 Igpo of the Silviries of Silviries from Silviries Silviri OSk
- onate-sulphate waters

 Cambrian Saine River Formation anhydrite gypsum and sait, Cap Mt.

 Formation shale and Mt. Clark Formation and stone. Expect maximum

 yields of 100 igpm of poor quality sulphate, chloride waters from th

 Sailos River sait and anhydrite, I igpm of poor quality sulphate waters from the Cap Mt. Formation shale, and 33 igpm of faitr quality

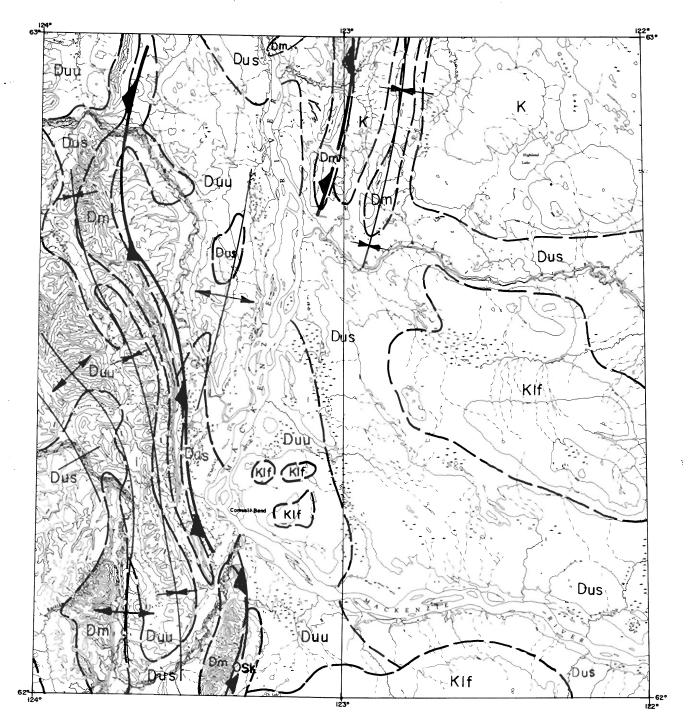
 waters from the Mt. Clark Formation shale, and 33 igpm of faitr quality

 waters from the Mt. Clark Formation smallers.
- Precambrian argillite, quartzite, and dolomite. Expect maximum yields of 25 Igpm of poor to fair quality waters

syncline

Map 3,

Tectonic symbols: ____ thrust fault with teeth indicating direction of dip; ____ anticline;



CAMSELL BEND BEDROCK HYDROGEOLOGY MAP RECONNAISSANCE

LEGEND OF GENERALIZED BEDROOK WIDROGEOLOGY MAP SHOWING GROUND-WATER PROBABILITY ALGOR MACKENZIE RIVER VALLEY FORT SIMPSON TO FORT MCPHERSON, NORTHWEST TERRITORIES

(Note: The entire study-area is underlain by widespread permafrost in the discontinuous permafrost zone; also, estimates of yields refer to probable, not absolute, maximum figures and to generally more highly disturbed, fractured, and porous zones within the formations)

Explanation

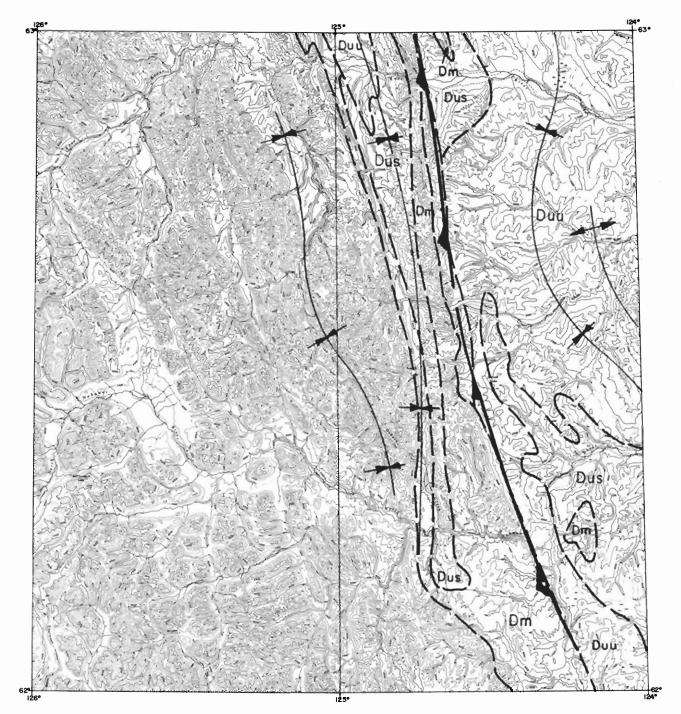
- Tertiary non-marine sand, gravel, conglomerate, shale, sandstone, coal. Expect maximum yields of 50 Igpm of generally fair to good quality waters
- Upper Cretaceous mainly non-marine sandstone and shale. Expect maximum yields of 25 Igpm of generally poor to locally fair quality
- Lower Cretaceous mainly marine shale and sandstone. Expect maximum yields of 1 Igpm of poor quality sulphate waters ĸ
- Upper Cretaceous Fort St. John Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
- Upper and Lover Cretaceous unnamed and undivided mainly marine shale and sandstone. Expect maximum yields of 5 Igpm of generally poor quality waters

 Carboniferous (Pennsylvanian) and Permian unnamed and undivided sandstone and conglomerace. Expect maximum yields of 25 Igpm of poor to locally fair quality waters
- Upper Devonian Redknife Formation mainly marine shale with minor sandstone and limestone. Expect maximum yields of 1 Igpm of generally poor quality waters Tectonic symbols:

- Upper Devonian unnered mainly non-marine shale, siltstone, limestone, and sandstone. Expect maximum yields of 5 Igpm generally poor to locally fair quality waters
- Upper Devonian Imperial Formation mainly non-marine shale and sand-stone. Expect maximum yields of 5 Igps of generally poor to locally fair quality waters
- Upper Devonian Kakisa Formation limestone. Expect maximum yields of 5 Igpm of poor to lecelly fear quality blcarbonate waters Upper Devonian Trout River and Tetche Formations consisting mainly of limestone with miner shale and sandstone. Expect maximum yields of 5 Igpm of poor te lecelly fair quality generally bicarbonate waters
- Upper Devonian Fort Simpson Formation marine shale and siltstone. Expect maximum yields of less than 1 Igpm of generally poor quality sulphate waters
- Middle Devonian unnamed and undivided mainly carbonate strata with minor shale and anhydrite. Expect maximum yields of 250 Igpm of variable quality bicarbonate-sulphate waters
 Middle Devonian Kee Searp Formation reefal and other limestones. Expect maximum yields of 100 Igpm of poor to locally fair quality generally bicarbonate, hard waters
- Middle Devonian Kee Scarp Formation Limestone and Hare Indian cal-careous shale. Expect maximum yields of 25 Igpm of variable qual-ity generally bicarbonate, hard waters thrust fault with teeth indicating direction of dip; —— anticline;

- Middle Devonian Hume Formation limestone. Expect maximum yields of 10 lgpm of variable quality generally blearbonate, hard vaters Middle Devonian Canol Formation shale. Expect maximum yields of 1 Lgpm of poor quality sulphate waters
- igpm of poor quality sulphate waters
 Middle Devonian Canol and Hare Indian Formations consisting mainly
 of shale. Expect maximum yields of 1 Igpm of poor quality bicarbonate-sulphate waters
- Middle Devonian Bear Rock Formation dolomite. limestone, and anhydrite. Expect maximum yields of 250 Igpm of very poor quality generally bicarbonate-sulphate waters
- Middle Devonian Hare Indian Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters

- on 1 igm on poor quality supmate waters Ordovician and Silurian unnamed and undivided dolomite and limest-one. Expect maximum yields of 10 igps of highly variable quality generally bicarbonate-sulphate waters Ordovician and Silurian Mount Kindle Formation dolomite and anhydrice item of remains man. Foresaited dolomite and shale. Expect maximum yields of 100 igps of generally poor to locally fair quality bicarb-onate-sulphate waters
- Constraints and the steers Committee and the steers of the
- Precambrian argillite, quartzite, and dolomite. Expect maximum yields of 25 Igpm of poor to fair quality waters



ROOT RIVER

BEDROCK HYDROGEOLOGY MAP RECONNAISSANCE

LEGEND OF GENERALIZED BEDROCK HYDROCEULOGY MAP TING GROUND-WATER PROBABILITY ALONG MACCINGIE RIYUR VALLEY PORT SIMPSON TO FORT MCPHERSON, NORTHWEST TERRITORIES

(Note: The entire study-are is underlain by widespread permafrost in the discontinuous permafrost zone: also, estimates of yields refer to probable, not absolute, maximum figures and to generally more highly disturbed, fractured, and porous zones within the formations)

Symbol Explanation

- Tertiary non-marine sand, gravel, coaglomerate, shale, sandstone, coal. Expect maximum yields of 50 lgpm of generally fair to good quality waters
- Upper Cretacesus mainly non-marine sandstone and shale. Expect maximum yields of 25 Igpm of generally poor to locally fair quality waters
- Lower Cretaceous mainly marine shale and sandstone. Expect maxim-um yields of 1 Igpm of poor quality sulphate waters
- Upper Cretaceous Fort St. John Turnstion shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters KIf
- Upper and Lower Cretabeeus unnamed and undivided mainly marine shale and sandstone. Expect maximum yields of 5 $I_{\rm 3pm}$ of generally poor quality vaters
- Carboniferous (Pennsylvanian) and Permian unnamed and undivided sand-stone and conglomerate. Expect maximum yields of 25 Igpm of poor to locally fair quality voters
- Upper Devonium Redenife Formation mainly marine shale with minor sandatone and limestone. Expect maximum yields of 1 Igpm of generally poor quality waters Tectonic symbols: ____ thrust fault with teeth indicating direction of dip; ____ anticline;

- Upper Devonian Imperial Formation mainly non-marine shale and send-stone. Expect maximum yields of 5 Igpm of generally poor to locally fair quality waters
- Upper Devonian Kakisa Formation limestoms. Expect maximum yields of 5 Igpm of poor to locally fair quality blcarbonate waters Upper Devenian Freet Alver and Tectoh Oremations commisting mainly of limestome with misor shale and sandatoms. Expect maximum yields of 5 Igpm of poor to locally fair quality penerally blcarbonate
- Upper Deruniam Fort Simpson Formation marine shale and siltstone. Expect maximum yields of less than 1 Igom of generally poor quality sulphate waters
- Middle Devonian unnamed and undivided mainly carbonate strata with minor shale and anhydrite. Expect maximus yields of 250 Igpm of variable quality bicarbonate-sulphate waters
 Middle Devonian Kee Scarp Formation reefal and other limestones.

 Expect maximus yields of 100 Igpm of poer to locally fair quality generally bicarbonate, hard vaters
- Middle Devomian Kee Scarp Formation limestone and Hare Indian cal-careous shale. Expect maximum yields of 25 Igpm of variable qual-ity generally bicarbonate, hard waters

- Middle Devonian Hume Formation linestone. Expect maximum yields of 10 Igpm of variable quality generally bicarbinate, hard waters Middle Devonian Canol Formation shale. Expect maximum yields of 1 Igpm of poor quality subplate waters Middle Devonian Canol and Hare Indian Pormations consisting mainly of shale. Expect maximum yields of 1 Igpm of poor quality bicarbonate-mulphate waters
- Dmc
- unate-suspects waters Middle Eventian Bear Mock Formation dolomits, limestone, and anhyd-rite. Expect maximum yields of 250 Igpm of very poor quality gene-rally bicarbonate-sulphate waters

- rally blearbomate-mulphate waters
 Middle Devonian Hare Indian Formation shale. Expect maximum yields
 of 1 (gam of poor quality sulphate waters
 Drdowickiam and Silurian unnamed and undivided dolomite and linestmes. Expect haximum yields of 10 Igms of highly variable quality
 generally bicarbomate-sulphate waters
 Drdowickiam and Silurian Momat Kindle Formation dolomite and anhydrite and Franklin Mtm. Formation delemite and shale. Expect maximum
 yields of 10 Igms of generally poor to locally fair quality bicarbomate-sulphate waters OSk
- conste-weighate waters

 Cambrian Salize River Furnation ambydrite gypsum and salt, Cap Mt.

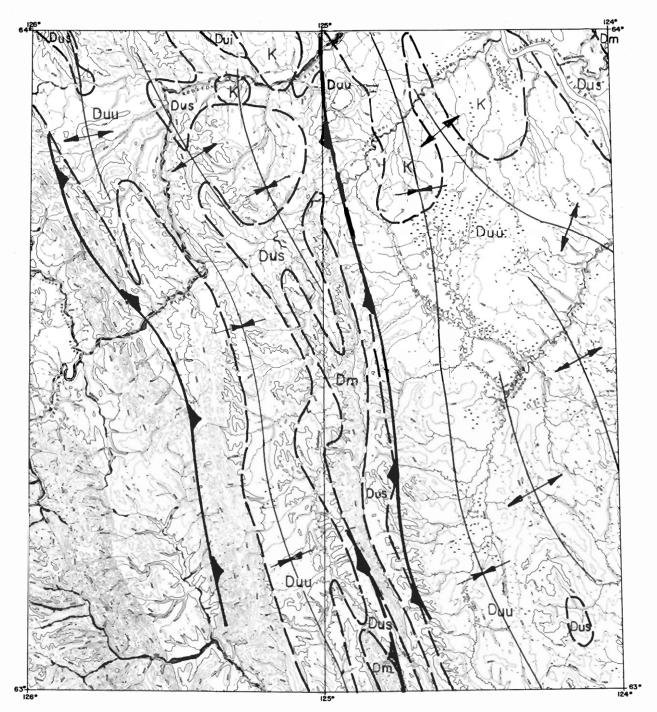
 Formation shale and Mt. Clark Formation sendatone. Expect mactum

 yields of 100 Igms of poor quality sulphate-chloride waters from the

 Saline River salt and ambydrite, 1 Igms of poor quality sulphate waters from the Cap Mt. Formation shale, and 25 Igps of fair quality

 vaters from the Mt. Clark Formation sandstone
- Precambrian argillite, quartrite, and dolomite. Expect maximum yields of 25 Igpm of poor to fair quality waters

syncline



DAHADINNI RIVER

RECONNAISSANCE BEDROCK HYDROGEOLOGY MAP

LEGEND OF GENERALIZED BEDROCK HYDROGEOLOGY MAP SHOWING CROUND-WATER PROBABILITY ALONG MACKENZIE RIVER VALLEY FORT SIMPSON TO FORT MCPHERSON, NORTHWEST TERRITORIES

(Note: The entire study-area is underlain by widespread permafrost in the discontinuous permafrost zone; also, extinates of yields refer to probable, not absolute, maximus figures and to generally more highly disturbed, fractured, and porous zones within the formations)

Symbol

Explanation

- Tertiary non-marine sand, gravel, conglowerate, shale, sandstone, coal. Happert maximum yields of 50 Igps of generally fair to good quality waters т
- Upper Circutateous mainly non-marine samistone and shale. Expect maximum yields of 23 Igpm of generally poor to locally fair quality waters Ku
- Lower Cretaceous mainly marine shale and sandstone. Expect maximum yields of 1 Igpm of poor quality sulphate waters ΚI
- Upper Cretaceous Fort St. John Formation shale. Expect maximum yields of 1 Igpm of pour quality sulphate waters
- Upper and Lower Cretaceous unmaned and undirided mainly marine shale and sandatoms. Expect maximum yields of 5 Igpm of generally poor quality vaters

 Carboniferous (Rennsylvanian) and Permian unnamed and undivided sendatoms and complementate. Expect maximum yields of 25 Igpm of poor to locally fair quality waters
- Upger Devonian Redknife Formation mainly marine shale with minor sandatone and limestone. Expect maximum yields of 1 Igpm of generally poor quality waters Tectonic symbols: - thrust fault with teeth indicating direction of dip; - anticline;

- Upper Devoniam umnamed mainly non-marios shale, siltstone, limestone, and sandstone. Expect maximum yields of 5 kpm generally poor to locally fair quality waters Dmc
- Upper Devonian Imperial Formation mainly non-marine shale and same stone. Expect maximum yields of 5 Igpm of generally poor to locally fair quality waters
- Upper Devonian Kakisa Formation limestone. Expect maximum yields of 5 Igpm of poor to locally fair quality bicarbonate waters Kppur Devonian Trown River and Tetcho Formations communiting mainly of limestone with minor shale and sandstone. Expect maximum yields of 5 Igpm of poor to locally fair quality generally bicarbonate waters
- Upper Devonian Fort Simpson Formation marine shale and siltatone. Expect maximum yields of less than 1 Igpm of generally poor quality sulphate waters
- Middle Devonian unnamed and undivided mainly carbonate strata with minor shale and anhydrite. Expect maximum yields of 250 Igpm of variable quality bicarbante-nulphate vaters
 Middle Devenian Kae Scarp Formation reefal and other limestomes.
 Expect maximum yields of 100 Igpm of poor to locally fair quality generally Sicarbonate, hard waters
- Drmki Middle Devonian Kee Scarp Formation limestome and Hare Indian cal-careous shale. Expect maximum yields of 25 lpm of variable qual-ity generally bicathonate, hard waters

- Middle Devociom Hume Formation linestone. Expect maximum yields of 10 Igpm of variable quality sensitally bicarbonate, hard witers Middle Devociom Canol Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate vaters Middle Devociom Canol and Hare Indian Formations commissing mainly of shale. Expect maximum yields of 1 Igpm of poor quality bicarbonate-sulphate waters
- Middle Devoniam Bear Rock Formation dolomite, limestone, and anhyd-rite. Expect maximum yields of 250 Igpm of very poor quality gene-rally bicarbonate-sulphate vaters
- Middle Devomian Hare Indian Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate vaters os
- OSk
- of 1 ign or poor quality suspents waters

 Ordoyican and Silurian summend and undivided dolomite and himstone. Expect maximum yields of 10 igns of highly wartable quality
 generally biphate vakers

 Crdewicklam and Siluriam Hount Kindle Formation delomite and ambydrite and Franklin Hen. Formation delomite and shale. Expert maximum
 yields of 100 igns of merally poor to locally fair quality bicarbonate-sulphate.
- onate-sulphase waters
 Cambrian Saline River Tornation anhydrite gypsum and sali, Cap Mt.
 Formation shale and Mt. Clark Formation sandatone. Espect maximum yields of 100 Igps of poor quality sulphate-chloride waters from the Saline River salt and sabydrite. I Igpm of poor quality sulphate waters from the Cap Mt. Formation shale, and 25 Igpm of fai; quality waters from the Mt. Clark Formation sandatone
- Precambrian argillite, quartzite, and dolomite. Expect maximum yields of 25 Igpm of poor to fair quality waters

- syncline



WRIGLEY BEDROCK HYDROGEOLOGY MAP RECONNAISSANCE

LEGEND OF GENERALIZED BEDROCK HYDROGEOLOGY MAP SHOWING GROUND-WATER PROSABILITY ALONG MACKERIE RIVER VALLEY FORT SIMPSON TO FORT MEPHERSON, NORTHWEST TERRITORIES

(Note: The entire study—area is underlain by widespread permafrost in the discontinuous permafrost zone; also, estimates of yields refer to probable, not absolute, maximum figures and to generally more highly disturbed, fractured, and porous zones within the formations)

Symbol

- Explanation Tertiary non-marine sand, gravel, conglomerate, shale, sandstone, coal. Expect maximum yields of 50 Igpm of generally fair to good quality waters
- Upper Cretaceous mainly non-marine sandstone and shale. Expect maximum yields of 25 Igpm of generally poor to locally fair quality
- Lower Cretaceous mainly marine shale and sandstone. Expect maximum yields of 1 Igpm of poor quality sulphate waters
- Upper Cretaceous Fort St. John Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
- Upper and Lower Cretaceous unnamed and undivided mainly marine shale and sandstone. Expect maximum yields of 5 Igpm of generally poor quality waters

 Carboniferous (Pennsylvanian) and Permian unnamed and undivided sandstone and complomerate. Expect maximum yields of 25 Igpm of poor to locally fair quality waters
- Upper Devonian Redknife Formation mainly marine shale with minor sandstone and limestone. Expect maximum yields of 1 Igpm of generally poor quality waters Tectonic symbols: ____ thrust familt with teeth indicating direction of dip; ____ anticline;

- byper Devotian unnamed mainly normarine shale, siltstone, limestone, and mandstone. Expect maxima yields of 5 Igpm generally poor to locally fair quality waters
 - Upper Devonian Imperial Formation mainly non-marine shale and sand-atoms. Expect maximum yields of 5 Igpm of generally poor to locally fair quality waters
- Upper Devonian Kakisa Formation limestane. Expect maximum yields of 5 igpm of pour to locally fast quality bicarbonate waters Upper Devonian Trout River and Tetcho Pormations constating mainly of limitations with minor shake and sendatione. Expect maximum yields of 5 igpm of poor to locally fair quality generally bicarbonate waters
- Upper Devonian Fort Simpaon Formation marine shale and siltstone.
 Expect maximum yields of less than 1 Igpm of generally poor quality sulphate waters
- Dm Middle Devonian unnamed and undivided mainly carbonate strata with miner whale and anhydrite. Expect maximum yields of 250 Igpm of variable quality bicarbonate-sulphate waters

 Dmk Middle Nevonian Kee Scarp Formation reafal and other limestones.

 Expect maximum yields of 100 Igpm of poor to locally fair quality generally bicarbonate, hard waters
- Drmki Middle Bevonian Fee Scarp Formation limestone and Hare Indian cal-careous shale. Expect maximum yields of 25 Igpm of variable qual-ity generally bicarbonate, hard waters

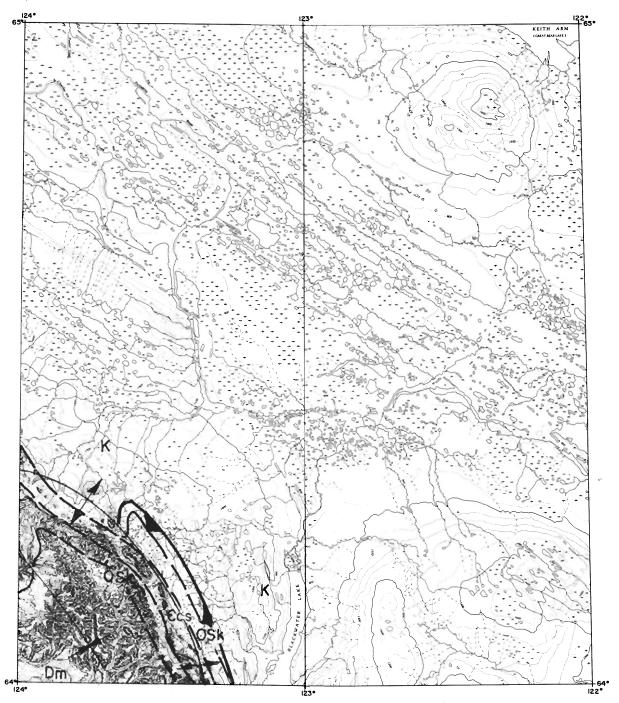
- Middle Devoniae **mme Formation limestone. Expect maximum yields of 10 lgps of variable quality generally bicarbonate, hard waters Middle Devoniae Camol Formation shale. Expect maximum yields of 1 lgpm of poor quality sulphase waters

- Middle Devonias Camol Fernation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters Middle Devonian Camol and Hare Indian Formations consisting mainly of shale. Expect maximum yields of 1 Igpm of poor quality bicarbonate-sulphate waters Middle Devonian Bear Rock Fernation dolonite, lineatene, and anhydrite. Expect maximum yields of 20 Igpm of poor quality generally bicarbonate-sulphate waters. Middle Devonian Bear Rock Fernation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters of the poor quality sulphate waters. Cambrian and Silvian summed and undivided dolonite and lineateness. Expect maximum yields of 10 Igpm of highly variable quality generally bicarbonate-sulphate waters. Ordevician and Silvian Nount Kindle Formation dolonite and anhydrite and Franklis Men. Formation dolonite and shale. Deport maximum yields of 100 Igpm of penerally poor to logally fair quality bicarbonate-sulphate waters.

 Cambrian Salism Ever Formation anhydrite gypsum and sali, Cap Mt. Formation shale and Mt. Clark Formation shale one of fair quality withhate waters from the Cap Mt. Formation shale, and of 1 Igpm of fair quality waters from the Cap Mt. Formation shale, and of 1 Igpm of fair quality waters from the Cap Mt. Formation shale, and of 1 Igpm of fair quality waters from the Cap Mt. Formation shale, and of 1 Igpm of fair quality waters from the Cap Mt. Formation shale, and of 1 Igpm of fair quality waters from the Cap Mt. Formation shale, and of 1 Igpm of fair quality waters from the Cap Mt. Formation shale, and of 1 Igpm of fair quality waters from the Cap Mt. Formation shale, and of 1 Igpm of fair quality waters from the Mt. Clark Formation smoothers.
- Precambrian argillite, quartzite, and dolomite. Expect maximum yields of 25 Igpm of poor to fair quality waters

- sympline

Mop 7



BLACK WATER LAKE

RECONNAISSANCE BEDROCK HYDROGEOLOGY MAP

LEGEND OF GENERALIZED BEDROCK HYDROGEOLOGY MAP
SHOWING GROUND-MATER PROBABILITY ALONG MACKENZIE RIVER VALLEY
FORT INFOOM TO FORT HYDESON, NORTHWEST TERRITORIES
(Note: The entire study area is underlain by widespread permafrost in
the discontinuous parafrost zone; also, estimates of
yields refer to probable, not absolute, maximum figures and to generally
more highly disturbed, fractured, and porous zones within the formations)

Symbol | Explanation

- Tertiary non-marine sand, gravel, conglowerate, shale, sandstone, coal. Expect maximum yields of 50 Igpm of generally fair to good
- Upper Cretaceous mainly non-marine sandstone and shale. Expect maximum yields of 25 Igpm of generally poor to locally fair quality waters
- Lower Cretaceous mainly marine shale and sandstone. Expect maximum yields of 1 Igpm of poor quality sulphate waters
- Upper Cretaceous Fort St. John Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters KIf
- Upper and Lower Cretaceous unnamed and undivided mainly marine shale and sametome. Expect maximum yields of 5 Igpm of generally poor quality waters
- Carbonifer (Pennsylvanian) and Pernian unnamed and undivided sand-stone and complomerate. Expect maximum yields of 25 Igpm of poor to locally fair quality waters
- Upper Devonian Redknife Formation mainly marine shale with minor sandstone and limestone. Expect maximum yields of 1 Igpm of generally poor quality waters

- Upper Devonian unnamed mainly non-marine shale, siltstone, limestone, and sandstone. Expect maximum yields of 5 Igpm generally poor to locally fair quality waters
- Upper Devonian Imperial Formation mainly non-marine shale and sand-stone. Expect maximum yields of 5 Igpm of generally poor to locally fair quality waters
- Upper Devonian Kakisa Formation limestome. Expect maximum yields of 5 Igps of poer to Locally fair quality blearbonate waters
 Upper Devonian Trout River and Tetho Formations commissing mainly of limestome with minor shale and sandstone. Expect maximum yields of 5 Igps of poor to locally fair quality generally blearbonate waters
- I, er Devonian Fort Simpson Formation marine shale and siltstone. In ject maximum yields of less than 1 Igpm of generally poor quality sulphate waters
- Middle Devision unnamed and undivided mainly carbonate strata with minor shale and anhydrite. Expect maximum yields of 250 Igpm of variable quality bicarbonate-sulphate waters
- Whiddle Devonian Kee Scarp Formation readal and other limestones.

 Expect maximum yields of 100 lpm of poor to locally fair quality generally bicarbonate, hard waters
- Drmki Middle Devonian Kee Scarp Formation limestone and Hare Indian cal-care was shale. Expect maximum yields of 25 Igpm of variable qual-ity generally bicarbonate, hard vaters
- Tectonic symbols: thrust fault with teeth indicating direction of dip; anticline;

- Drmh Middle Devonian Hume Formation limestone. Expect maximum yields of 10 Igpm of variable quality generally bicarbenate, hard waters
 Drmc Middle Devonian Canol Formation shale. Deset maximum yields of 1 Igpm of poor quality sulphate waters
 Drmc Middle Devonian Canol and Hare Indian Formations consisting mainly of shale. Expect maximum yields of 1 Igpm of poor quality bicarbonate-sulphate waters
- onate-sulphate waters
 Middle Devendam Bear Rock Formation dolonits, limestone, and anhydrits. Expect maximum yields of 250 Igpm of very poor quality generally bicarbenate-sulphate waters
 Middle Devendam Hare Indiam Formation shale. Expect maximum yields of I Igpm of poor quality sulphate waters

- On tight as poor quality sulphate vaters

 Ordovician and Silurian unamed and undivided dolomite and limestone. Expect haximum yields of 10 Igps of highly variable quality
 generally blicarbonate-sulphate vaters

 Ordovician and Silurian Mount Kindle Formation dolomite and anhydrite and Franklin Mrn. Formation dolomite and shale. Expect maximum
 yields of 100 Igps of generally poor to locally fair quality bicarbonate-sulphate waters
- onate-sulphake waters

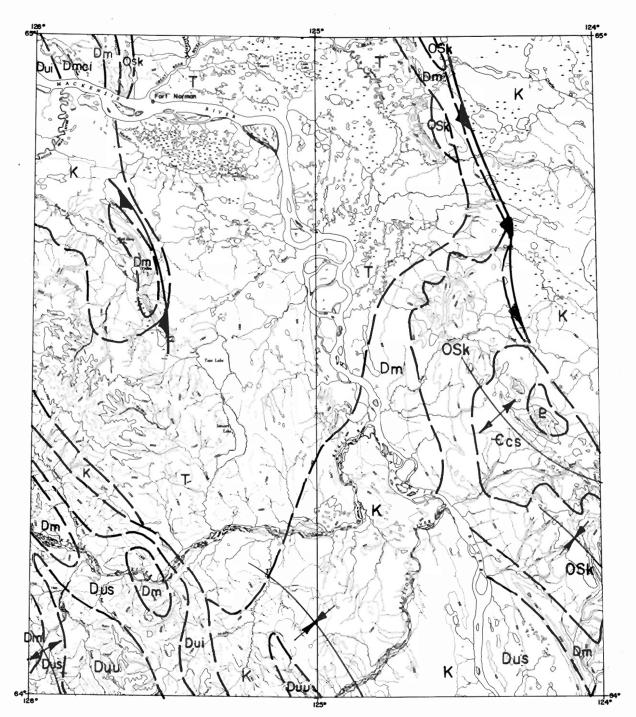
 Cambrian Saline River Fornation anhydrice gypum and malt, Cap Mt.

 Fornation shake and Mt. Clark Fornation sandatone. Expect maximum

 yields of 100 1zmm of poor quality sulphate-chief waters from

 Saline River malt and anhydrite, 1 Igpm of poor quality sulphate waters from the Cap Mt. Fornation shake, and 25 Igpm of fair quality

 waters from the Mt. Clark Fornation shakes and 25 Igpm of fair quality
- Precambrian argillite, quartzite, and dolomite. Expect maximum yield of 25 Igpm of poor to fair quality waters



FORT NORMAN

RECONNAISSANCE BEDROCK HYDROGEOLOGY MAP

LEGEND OF GENERALIZED BEDROCK HYDROGEOLOGY MAP SHOWING GROUND-WATER PROBABILITY ALONG MACKENZIE RIVER VALLEY FORT SIMPSON TO FORT McPHERSON, NORTHWEST TERRITORIES

(Note: The entire study-area is underlain by widespread permafrost in the discontinuous permafront zone; also, extmates of yields refer to probable, not absolute, maximum figures and to generally more highly disturbed, fractured, and porous zones within the formations)

Symbol |

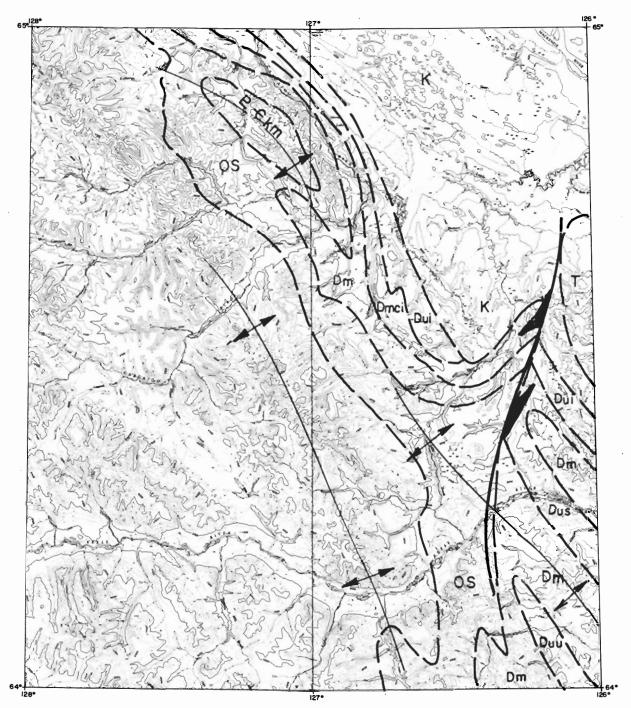
- Tertiary non-marine sand, gravel, conglomerate, shale, sandstone, coal. Expect maximum yields of 50 Igpm of generally fair to good quality waters $\,$
- Upper Cretaceous mainly non-marine sandstone and shale. Expect maximum yields of 25 Igpm of generally poor to locally fair quality waters
- Lower Cretaceous mainly marine shale and sandstone. Expect maximum yields of 1 Igpm of poor quality sulphate waters
- Upper Cretaceous Fort St. John Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
- Upper and Lower Cretaceous unnamed and undivided mainly marine sha-le and sandstone. Expect maximum yields of 5 Igpm of generally poor quality waters
- Carboniferous (Pennsylvanian) and Permian unnamed and undivided sand-stone and complomerate. Expect maximum yields of 25 Igpm of poor to locally fair quality waters
- Upper Devonian Redknife Formation mainly marine shale with minor sandstone and limestone. Expect maximum yields of 1 Igpm of generally poor quality waters

- Upper Devonian unnamed mainly non-marine shale, siltstone, limestone, and sammatone. Expect maximum yields of 5 Igpm generally poor to locally fair quality vaters
- Upper Devonian Imperial Formation mainly non-Mmarine shale and sand-stone. Expect maximum yields of 5 Igpm of generally poor to locally fair quality waters Dui
- Upper Devonian Kakisa Formation limestone. Expect maximum yields of 5 Igpm of poor to locally fair quality bicarbonate waters Upper Devonian Trout River and Tetche Formations constating mainly of limetrone with minor shale and sandstone. Expect maximum yields of 5 Igpm of poor to locally fair quality generally bicarbonate waters
- Upper Devonian Fort Simpson Fornation marine shale and siltstone. Expect maximum yields of less than 1 Igpm of generally poor quality swiphate waters
- Middle Devonian unnamed and undivided mainly carbonate strata with minor shale and anhydrite. Expect maximum yields of 250 Igpm of variable quality bicarbonate-sulphate waters
- Middle Devonian Kee Scarp Formation reefal and other limestones. Expect maximum yields of 100 Igpm of poor to locally fair quality generally bicarbonate, hard waters
- Drmki Middle Devonian Kee Scarp Formation limestone and Hare Indian cal-carrows shale. Expect maximum yields of 25 Igpm of variable qual-ity generally bicarbonate, hard waters
- Tectonic symbols: ____ thrust fault with teeth indicating direction of dip; ____ anticline;

:

- Middle Devonian Hume Formation limestone. Expect maximum yields of 10 Igpm of variable quality generally bicarbomete, hard waters Middle Devonian Camol Formation shake. Expect maximum yields of 1 Igpm of poor quality sulphate waters Middle Devonian Camol and Hare Indian Formations consisting mainly of shake. Expect maximum yields of 1 Igpm of poor quality bicarbonate-sulphate waters
- onate-sulpnate waters
 Middle Devonian Bear Rock Formation dolomite, limestone, and anhydrite. Expect maximum yields of 250 Igpm of very poor quality generally bicarbonate-sulphate waters

- rally bicarbonate-sulphate waters
 Middle Devonian Hare Indian Formation shale. Expect maximum yields
 of 1 ignm of poor quality surphate waters
 Ordowician and Silurian unasmed and undivided dolomite and limestone. Expect maximum yields of 10 ignm of highly variable quality
 generally bicarbonate-mulphate waters
 Ordowician and Silurian Mount Kindle Formation dolomite and anhydrite and Franklin Htm. Formation dolomite and shale. Expect maximum
 yields of 10 ignm of generally poor to locally fair quality bicarbonate-mulphate water generally
- onate-mulphate waters
 Cambrium Saline Kiver Formation anhydrite gypsum and salt, Cap Mt.
 Formation shale and Mt. Clark Formation sandstone. Expect maximum
 ytelids of 100 Igps of poor quality sulphate-chloride waters from the
 Salium Kiver salt and anhydrite, 1 Igps of poor quality sulphate wa
 ters from the Cap Mt. Formation shale, and 25 Igps of fair quality
 waters from the Mt. Clark Formation sandstone
- Precambrian argillite, quartrite, and dolomite. Expect maximum yields of 25 Igpm of poor to fair quality waters



CARCAJO U CANYON

RECONNAISSANCE BEDROCK HYDROGEOLOGY MAP

LIGEND OF GENERALIZED BEDROOK MYCHOCHOLOGY MAP
SHOWING GROUND-WATER PROBABILITY ALONG MACCINEZEE RIVER VALLEY
FORT BIMPSON TO FORT MCPHERSON, NORTHWEST TERRITORIES

(Note: The entire study-area is underlain by widespread permafrost in the discontinuous permafrost zone: also, estimates off yields refer to probable, not absolute, maxime figures and to generally more highly disturbed, fractured, and porous roses within the formations)

Symbol Explanation

- Tertiary non-marine sand, gravel, conglomerate, shale, sandstone, coal. Expect maximum yields of 50 Igpm of generally fair to good quality waters т
- Κu Upper Creteceous mainly non-marine sandstone and shale. Expect maximum yields of 25 Igpm of generally poor to locally fair quality
- Lower Cretaceous mainly marine shale and sandstone. Expect maxim-um yields of 1 Igpm of poor quality sulphate waters
- Upper Cretaceous Fort St. John Formation shale. Expect maximum yields of I iggs of poor quality sulphate waters
- Upper and lower Cretaceous unnamed and undivided mainly merime shale and assestome. Expect maximum yields of 5 Igpm of generally poor quality waters

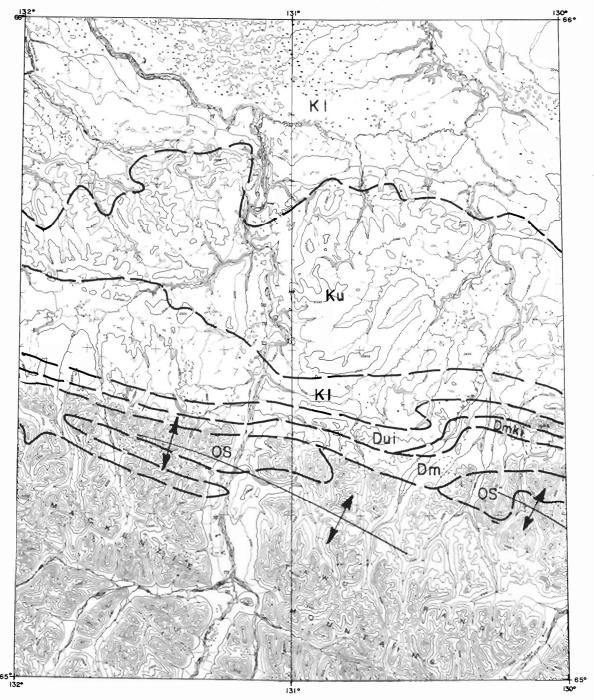
 Carboniferom (Pennay-lyanies) and Permian unnamed and undivided sandstone and complementate. Dippet maximum yields of 25 Igpm of poor to locally fair quality waters
- Upper Devonian Redknife Formation mainly marine shale with minor sandstone and limestone. Expect maximum yields of 1 Igpm of generally poor quality waters Tectonic symbols: ____ thrus: familt with teeth indicating direction of dip; ____ anticline;

- Upper Devonian unnamed mainly non-marine shale, siltstone, limestone, ané aandstone. Expect maximum yields of 5 Igpm generally poor to locally fair quality waters
- Upper Devonian Imperial Formation mainly non-marine shale and sand-stone. Expect maximum yields of 5 Igpm of generally poor to locally fair quality waters
- Upper Devonian Cakina Formation limestors. Expect markinum yields of 5 Igpm of poor to locally fair quality bicarbonate waters Upper Devonian Trout River and Teccho Fermations commissing mainly of limestone with minor shale and sandanes. Expect maximum yields of 5 Igpm of poor to locally fair quality generally bicarbonate waters
- Upper Devonian Fort Simpson Formation marine shale and siltitume-Expect maximum yields of less than 1 Igpm of generally poor qual-ity sulphate waters
- Middle Devonian unnamed and unalviced mainly cariomate strata with minor shale and anhydrite. Espect marginum yields of 250 Igpm of variable quality blear-bonate-wulphate wysters
 Middle Devonian Ess Scarr Formation reefal and other limestones.
 Expect maximum yields off 100 Igpm of poor to locally fair quality generally blear-bonate, hard waters
- Drmki Middle Devonian for Scarp Formation linestone and Nare Indian cal-careous shale. Expect maximum yields of 3 Igpm of wariable qual-ity generally bicarbonate, hard waters

- Drmh Middle Devonian Nume Formation limestone. Expect maximum yields of 10 Igps of variable quality generally bicaisonate, hard waters Drmc Middle Devonian Canol Formation shale. Expect maximum yields of 1 Igps of poor quality sulphate waters Drmc! Middle Devonian Canol and Hare Indian Formations consisting mainly of shale. Expect maximum yields of 1 Igps of poor quality bicarbonate-sulphate waters

 Drmbr Middle Devonian Bear Rock Formation dolomite, libus come, and anhydrite. Expect maximum yields of 250 Igps of very goor quality generated by the property of the prop onge-sulphate waters
 Camarians Saline River Formation anhydrite gypsum and salt, Cap Mt.
 Formation shale and Mt. Clark Formation sandstone. Expect maximum
 yields of 100 Igpn of poor quality sulphate-chloride waters from the
 Saline River sale and anhydrite, J. Igpn of poor quality sulphate waters from the Cap Mt. Formation shale, and 25 Igpn of fair quality
 waters from the Mt. Clark Formation annalstone

Precembrian argillite, quartzite, and dolomite. Expect maximum yieldm of 25 Igpm of poor to fair quality waters syncline



UPPER RAMPARTS RIVER

RECONNAISSANCE BEDROCK HYDROGEOLOGY MAP

LEGEND OF GENERALIZED BEDROCK HYDROGEOLOGY MAP SHOWING GROUND-WATER PROBABILITY ALONG MACKENZIE RIVER VALLEY FORT SIMPSON TO FORT MCPHERSON, NORTHWEST TERRITORIES

(Note: The entire study-area is underlain by widespread permafrost in the discontinuous permafrost zone; also, estimatem of yields refer to probable, not absolute, maximum figures and to generally more highly disturbed, fractured, and porous zones within the formations)

Symbol

Explanation

- Tertiary non-marine sand, gravel, conglowerate, shale, sandstone, coal. Expect maximum yields of 50 Igpm of generally fair to good quality waters
- Upper Cretaceous mainly non-marine sandstone and shale. Expect maximum yields of 25 Igpm of generally poor to locally fair quality waters
- Lower Cretaceous mainly marine shale and sandstone. Expect maximum yields of 1 Igpm of poor quality sulphate waters Κl
- Upper Cretaceous Fort St. John Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
- Upper and Lower Cretaesesus unnamed and undivided mainly marine shale and sandatone. Expect maximum yields of 5 Igpm of generally poor quality vaters

 Carboniferous (Pennsylvanian) and Permian unnamed and undivided sandatone and congloserate. Expect maximum yields of 25 Igpm of poor to locally fair quality waters
- Upper Devonian Redknife Formation mainly marine shale with minor sandstone and limestone. Expect maximum yields of 1 Igpm of generally poor quality waters Tectonic symbols: ____ thrust fault with teeth indicating direction of dip; ____ anticline;

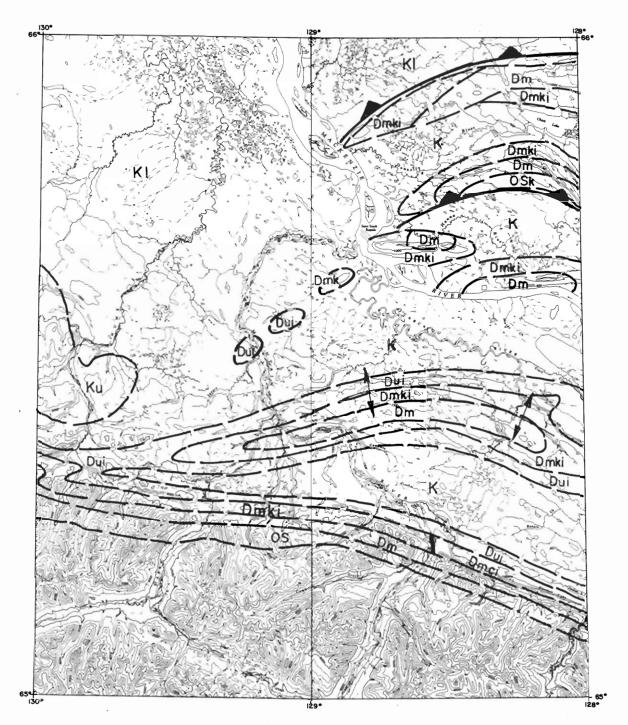
- Upper Devonian unnamed mainly non-marine shale, siltstone, limeatone, and sandstone. Expect maximum yields of 5 Igpm generally poor to locally fair quality waters Dmc
- Upper Devonian Imperial Formation mainly non-marine shale and sand-stume. Expect maximum yields of 5 Igpm of generally poor to locally fair quality waters
- Upper Devonian Kakisa Formation limestone. Expect maximum yields of 5 Igpm of poor to locally fair quality bicarbonate waters
 Upper Devonian Troot River and Tetche Termations consisting mainly
 of limestone with since shale and manditone. Expect maximum yields
 of 5 Igpm of poor to locally fair quality generally bicarbonate vaters
- Upper Devonian Fort Simpson Formation marine shale and siltstone. Expect maximum yields of less than 1 Igpm of generally poor quality sulphate waters $\,$
- Middle Devonian unnamed and undivided mainly carbonate strata with minor shale and anhydrite. Expect maximum yields of 250 Igom of variable quality bicarbonate-sulphate vakers
 Middle Devonian Kes Scarp Formation remfal and other limeatones.
 Expect maximum yields of 100 Igom of poor to locally fair quality generally bicarbonate, hard waters
- Drnki Middle Devonian Kee Scarp Formation linestone and Hare Indian cal-careous shale. Expect maximum yields of 25 Igpm of variable qual-ity generally bicarbonate, hard waters

- Middle Devonian Hume Formation Limentone. Expect maximum yields of 10 Igpm of variable quality generally bicarbonate, hard waters Middle Devonian Canol Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters Middle Devonian Canol and Mare Indian Formations consisting mainly of shale. Expect maximum yields of 1 Igpm of poor quality subject monate-sulphate waters
- Middle Devonian Bear Rock Formation dolomite, limestone, and anhyd-rite. Expect maximum yields of 250 Igpm of very poor quality gene-rally bicarbonate-sulphate waters
- Middle Devoism Hare Indian Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters Ordovictian and Silurian unnamed and undivided dolomite and limestone. Expect maximum yields of 10 Igpm of highly variable quality generally bitachemate-sulphate waters. os
- OSk
- generally blearbonate-sulphate vaters

 Ordovictam and Silurtan Mount Kindle Formation dolomite and anhydrite and Franklin Mtm. Formation dolomite and shale. Expect maximum yields of 100 Igpm of generally poor to locally fair quality blearbonate-sulphate waters

 Cambrian Saline River Formation subpirite gypsum and salk, Cap Mt. Formation shale and Mt. Clark Formation sendatons. Expect maximum yields of 100 Igpm of poor quality sulphate-chlorice waters from the Saline River salt and anhydrite, 1 Igpm of poor quality sulphate waters from the Cap Mt. Formation shale, and 25 Igpm of fair quality waters from the Cap Mt. Formation shale, and 25 Igpm of fair quality waters from the Mt. Clark Formation sandstone
- Precambrian argillite, quartzite, and dolomite. Expect maximum yields of 25 Igpm of poor to fair quality waters

- syncline Map II



SANS SAULT RAPIDS

RECONNAISSANCE BEDROCK HYDROGEOLOGY MAP

LEGEND OF GENERALIZED BEDROCK HYDROGEOLOGY MAP
SHOWING GROUND-MATER PROBABILITY ALONG MACCOMILE TYPER VALLEY
FORT SIMPSON TO FORT MC THERSON, NORTHWEST TERRITORIES

(Note: The entire study-area is underlain by widespread permafrost in the discontinuous permafrost mose; also, extinates of yields refer to probable, not subsolute, maximum figures and to generally more highly disturbed, fractured, and persua zones within the formations)

Symbol | Explanation

- Tertiary non-marine sand, gravel, conglomerate, shale, sandstone, coal. Expect maximum yields of 50 Igpm of generally fair to good quality waters
- Upper Cretaceous mainly non-marine sandstone and shale. Expect maximum yields of 25 Igpm of generally poor to locally fair quality
- Lower Cretaceous mainly marine shale and sandstone. Expect maximum yields of 1 Igpm of poor quality sulphate waters
- Upper Cretaceous Fort St. John Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters KIf
- Upper and Lover Cretace-us unnamed and undivided mainly marine shale and sandstorie. Expect maximum yields of 5 Igpm of generally poor quality variers

 Carboniferous (Pennsylvmian) and Permian unnamed and undivided sandstons and complomerate. Expect maximum yields of 25 Igpm of poor to locally full quality waters
- Upper Devoni an Backsife Formation mainly marine shale with minor sandatone and limestone. Expect maximum yields of 1 Igpm of generally poor quality witers

- Upper Devonion unnamed mainly non-marine shale, siltstone, limestone, and sandatoms. Expect maximum yields of 5 Igpm generally poor to locally fair quality waters
- Upper Devonian Imperial Pormation makiny non-marine shale and sand-stone. Expect maximum yields of 5 Impu of generally poor to locally fair quality waters
- Upper Devonian Kakisa Formerior limentime. Expect maximum yields of 5 Igpm of poor to locally fair quality bicarbonate waters in Upper Devonian Trout River and Tetcho Formations consisting mainly of limestone with minor shale and sandatone. Expect maximum yields of 5 Igpm of poor to locally fair quality generally bicarbonate waters.
- Upper Devonian Fort Simpson Formation marine shale and siltstone. Expect maximum yields of less than 1 Igpm of generally poor quality sulphate waters
- Middle Devonian unnamed and underwhed mainly carbonate strata with minor shale and anhydrite. Expect maximum yields of 250 Igpm of variable quality bicarbonate-sulphate waters
- Middle Devonian Kee Scarp Forusiion reefal and other limestones.

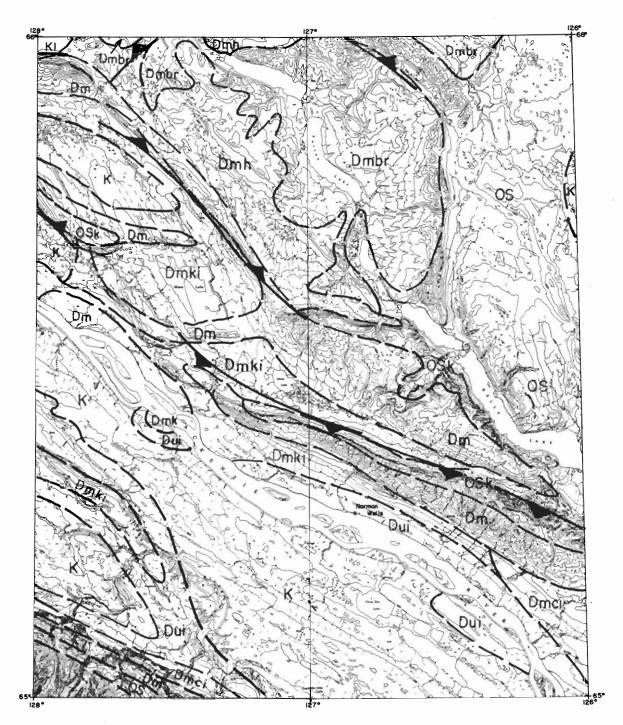
 Expect maximum yields of 100 I gpm of poor to locally fair quality generally bicarbonate, hard wasters
- Middle Devonian Kee Scarp Formation limentone and Mare Indian cal-careous shale. Expect maximum yields of 25 Ignm of variable qual-ity generally bicarbonate, hard waters Tectonic symbols: - thrust fault with teeth indicating direction of dip; - anticline;

- Middle Devonian Hume Formation limestane. Expect maximum yields of 10 Isps of variable quality generally bicarbonate, hard waters Middle Devonian Canol Formation shale. Expect maximum yields of 1 Isps of poor quality sulphate waters is Middle Devonian Canol and Mare Indian Formations consisting mainly of imake Expect maximum yields of 1 Isps of poor quality bicarbonate—wiphate waters / Middle Devonian Bear Rock Formation dolomite, limestone, and anhydrite. Expect maximum yields of 250 Isps of very poor quality generally bicarbonate-sulphate waters with the property of the property of
- onate-augment waters!

 Cambrian Saline River Formation anhydrite gypsum amd mair, Cap Mt.

 Formation shale and Mt. Clark Formation mundstone. Expect maximum yields of 100 Igps of poor quality sulphame-chloride extens from the Saline River salt and anhydrite, 1 Igpm of poor quality sulphame waters from the Cap Mt. Formation shale, and 25 Igps of fair quality waters from the Mt. Clark form shale, and 25 Igps of fair quality waters from the Mt. Clark formation sandstone
- Precambrian argillite, quartzite, and dolomite gx ect maximum yields of 25 Igpm of poor to fair quality waters

syncline Map 12



NORMAN WELLS

BEDROCK HYDROGEOLOGY MAP RECONNAISSANCE

LEGEND OF GENERALIZED BEDROX STEMSOGGEOUT MAP
SHOWING GROUND-WATER PROBABILITY ALGO MACCOUNTER STURE VALLEY
FORT SIMPSON TO FORT MCPHERSON, NORTHWEST TERRITORIES

(Note: The entire study-area is underliked by videspread permafrost in
the discontinuous permafront zone; also, estimates of
yields refer to probable, not absolute, maximum figures and to generally
more highly disturbed, fractures, and porous zones within the formations)

Symbol .

- Ixplanation Tertiary non-marine sand gravel, conglomerate, shale, sandstone, coal. Expect maximum yields of 50 Igpm of generally fair to good quality waters
- Upper Cretaceous mainly non-marine sandstone and shale. Expect maximum yields of 25 Igpm of generally poor to locally fair quality waters
- Lower Cretaceous mainly marine shale and sandstone. Expect maximum yields of 1 Igpm of poor quality sulphate waters
- Upper Cretaceous Fort St. John Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
- Upper and Lower Cretacrous unnamed and undivided mainly marine shale and sandstone. Expect maximum yields of 5 Igpm of generally poor quality waters
- Carboniferous (Pennylvaniam) and Permian unnamed and undivided sand-stone and conglomeries. Employed maximum yields of 25 Igpm of poor to locally fair quarky wavers
- Upper Devonian Redknife Formation mainly marine shale with minor sandstone and limestone. Expect maximum yields of 1 Igpm of generally poor quality waters

- Upper Devonian unnamed mainly non-marine shale, siltstone, limestone, and sandstone. Expect maximum yields of 5 Igpm generally poor to locally fair quality waters
- Upper Revoction Imperial Formation mainly non-marine shale and sand-stone. Expect maximum yields of 5 Igpm of generally poor to locally fair quality waters
- Upper Devonian Kakisa Formation limistome. Expect maximum yields of 5 Igps of poor to locally fair quality bicarbonate waters Upper Devaniam Trout River and Tectho Formations commissing mainly of limitoms with minor shale and sandatone. Expect maximum yields of 5 Igps of poor to locally fair quality generately bicubowance.
- Upper Devonian Fort Simpson Formation marine shale and siltstone. Expect maximum yields of less than 1 Igpm of generally poor quality sulphase waters
- Middle Devenies unmaned and undivided mainly carbonate strata with minor shall and any write. Expect maximum yields of 250 Igpm of variable quality bicarbonate-sulphate waters
- Hiddle Devonian Kee Scarp Formation reefal and other limestones.

 Expect maximum yields of 100 Igpm of poor to locally fair quality generally bicarbonate, hard waters
- Drmki Middle Devonian Kee Scarp Formation limestone and Hare Indian cal-careous shale. Expect maximum yields of 23 Igpm of variable qual-ity generally bix-deviouste, hands wakers

- Hiddle Devonian Hume Formation limestone. Expect maximum yields of 10 Igpm of variable quality generally bicarbonate, hard waters Middle Devonian Canol Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters Hiddle Devonian Canol and Hare Indian Formations commaisting mainly of shale. Expect maximum yields of 1 Igpm of poor quality bicarbonate-sulphate waters
- Middle Devonian Bear Rock Formation dolomite, limestone, and anhydrite. Expect maximum yields of 250 Igpm of very poor quality generally bicarbonate-sulphate waters
- Middle Devonian Hare Indian Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters

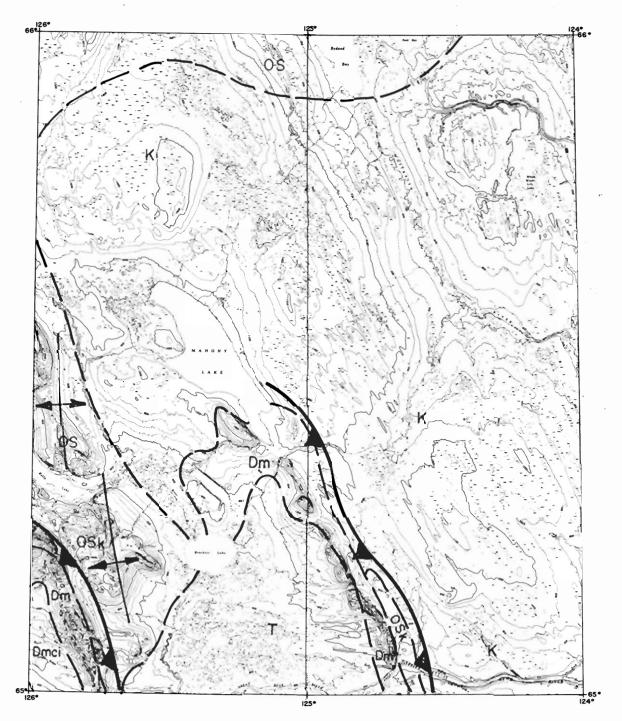
- of 1 igps of poor quality sulphate waters
 Ordovician and Silurian unnamed and undivided dolomite and limestone. Expect maximum yields of 10 igps of highly variable quality
 generally bicarbonate-sulphate vaters
 Ordovician and Silurian Mount Kindle Formation dolomite and anhydrite and Franklin Mtn. Formation dolomite and whale. Expect maximum
 yields of 100 igps of generally poor to unactly class quality bicarbonate-sulphate waters
 Cambrian Salwe Etver Formation anhydrite gypsum and salt, Cap Mt.
 Formation shale and Mt. Clrk Formation sandatone. Expect maximum
 yields of 10 igps of poor quality yulphate-choirde waters from the
 Saline Etver salt and anhydrite, 1 igps of poor quality sulphate waters from the Cap Mt. Formation shale, and 25 igps of fair quality
 waters from the Mt. Clark Formation sandatone

Precambries argilite, quartrite, and dolomite. Expect maximum yields of 25 Iggs of poor to fair quality waters

— syncline

Mop 1 Map 13

▲ thrust fault with teeth indicating direction of dip; anticline; Tectonic symbols:



MAHONY LAKE

BEDROCK HYDROGEOLOGY MAP RECONNAISSANCE

LEGEND OF GENERALIZED BEDROCK HYDROGEOLOGY MAP SHOWING GROUND-WATER PROBABILITY ALONG MACKENZIE RIVER VALLEY FORT SIMPSON TO FORT M-PHERSON, NORTHWEST TERRITORIES

(Note: The entire study-area is underlain by videapread) permafront in the biacontinuous permafront zone; also, entimizes of yields refer to probable, not absolute, maximum figures and to generally more; highly disturbed, fractured, and porous zones within the formations)

Symbol

Explanation

- Tertiary non-marine sand, gravel, conglowerst#, mbale, sandstone, coal. Expect maximum yields of 50 Igpm of gemerally fair to good quality waters
- Upper Cretaceous mainly non-marine sands tome and shale. Expect maximum yields of 25 Igpm of generally poor 6 locally fair quality waters
- Lower Cretaceous mainly marine shale and sandstone. Expect maxim-um yields of 1 Igpm of poor quality sulphate waters
- Upper Cretaceous Fort St. John Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate watera KIf
- Upper and Lower Cretaceous unnamed and undivided mainly marine shale and sandstone. Expect maximum yields of 5 Igpm of generally poor quality vaters

 Carboniferou: ("Punsylvaniam) and Permian unnamed ami undivided sandstone and consyleariate. Expect maximum yields of 25 Igpm of poor to locally fait quality waters
- CPa
- Upper Devonian Redknife Formation mainly marin α shall with minor samatone and limestone. Expect maximum yield α of ligpm of generally poor quality waters

- Upper Devoniam ummamed mainly non-marine shale, siltstone, limestone, and sandstone. Expect maximum yields of 5 Igpm generally poor to locally fair quality waters
 - Upper Devoniam Imperial Formation mainly non-marine shale and sand-stone. Expect maximum yields of 5 Igpm of generally poor to locally fair quality waters
- Upper Devonian Kakiss Formation limestone. Expect maximum yields of 5 Igpm of poor to locally fair quality bicarbonate waters Upper Devonian Trout River and Fatch Formations consisting mainly of limestone with minor shale and sandstone. Expect maximum yields of 5 Igpm of poor to locally fair quality generally bicarbonate waters
- Upper Devonian Fort Simpson Formation marine shale and siltstone. Expect maximum yields of less than 1 Igpm of generally poor quality sulphate waters
- Middle Devonian unnamed and undivided main'sly Corbonate strata with minor shale and anhydrite. Expect maximum yleds of 250 Tgpm of variable quality bicarbonate-sulphate watches
- Dmk Middle Devonian Kee Scarp Formation reefal and other limestones.

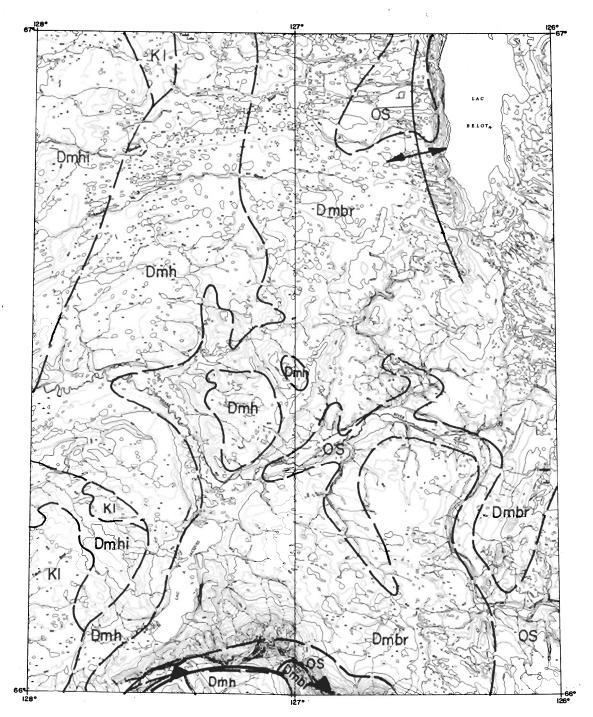
 Expect maximum yields of 100 lgpm of poor to locally fair quality generally bicarbonate, hard waters
- Drmki Middle Devonian Kee Scarp Formation limestone and Mare 7-44 an cal-careous shale. Expect maximum yields of 25 Igpm of var 12me qual-ity generally bicatbonate, hard waters

- Middle Devonian Hume Formation limentome. Expect maximum yields of 10 Igps of variable quality generally bloationate, hard vaters Middle Devonian Canol Formation shake. Expect maximum yields of 1 Igps of poor quality sulphare suspers Middle Devonian Canol and Have Indian Formations committing mainly of shale. Expect maximum yields of 1 Igps of poor coulity sulphare vaters Middle Devonian Bear Rock Formation dolonite, linestone, and anhydrite. Expect maximum yields of 250 Igps of very poor quality generally bloathonate-sulphate waters Middle Devonian Bears Indian Formation shale. Expect maximum yields of 1 Igps of joor quality unlphate waters Ordovician and Silverian unmanded said and variable quality generally bloathonate-sulphate waters Ordovician and Silverian Mount Kindle Formation dolonite and shale. Expect maximum yields of 10 Igps of highly variable quality generally bloathonate-sulphate vaters Ordovician and Silverian Mount Kindle Formation dolonite ame anhydrite was Figsk line Mine Formation olosite and shale. Expect maximum yields of 10 Igps of senerally poor to locally fair quality bloathomatic-sulphate vaters or locally fair quality bloathomatic-sulphate vaters or ordovician salies River Igns of our quality sulphate-choic Tweet travers from the Salies River Igns of our quality sulphate-choic Tweets from the Kalles River Igns of our quality sulphate-choic Tweets from the Kelles Kormation shale, and 25 Igns of of liq quality vaters from the Kt. Clark Formation sandsone. Expect maximum
- Precambrian argillite, quartzite, and dolomite. Expect maximized of 25 Igpm of poor to fair quality waters

- syncline

Map 14

thrust fault with teeth indicating direction of dip; anticline;



LAC BELOT BEDROCK HYDROGEOLOGY MAP RECONNAISSANCE

LECEND OF GENERALIZED BEDROCK HYDROGEDLOGY MAP
SHOWING GROUND-WATER PROBABILITY ALONG MACKENZIE RIVER VALLEY
FORT SIMPSON TO FORT HEPHERSON, NORTHWEST TERRITORIES
(Note: The entire study-area is underliab by videopread permafroat in
the discontinuous permafroat zone; also, estimates of
yields refer to probable, not absolute, mackimum figures and to generally
more highly disturbed, fractured, and porous some within the formations)

Symbol Explanation

- Tertiary non-marine sand, gravel, conglomerate, shale, sandatone, coal. Expect maximum yields of 50 Igpm of generally fair to good quality waters
- Upper Cretaceous mainly non-marine sandstone and shale. Expect maximum yields of 25 Igpm of generally poor to locally fair quality waters
- waters
 Lower Cretacoous mainly marine shale and sandstone. Expect maximum yields of 1 Igpm of poor quality sulphate waters
- Upper Crataceous Fort St. John Fermation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
- Upper and Lower Cretaceous unnamed and undivided mainly marine shale and sandstone. Expect maximum yields of 5 Igpm of generally poor quality waters
- Carboniferous (Pennsylvanian) and Peria mnamed and undivided sand-stone and conglomerate. Expect maximum yields of 25 Igpm of poor to locally fair quality waters
- Upper Devotion Radknife Formation mainly marine shale with minor sandstone and limestone. Expect maximum yields of 1 Igpm of generally poor quality waters

- Upper Devonian unnamed mainly non-marine shale, siltstone, limestone, and sandstone. Expect maximum yields of 5 Igpm generally poor to locally fair quality waters
- Upper Devonian Imperial formation mainly non-marine shale and sand-stone. Expect maximum yields of 5 Igps of generally poor to locally fair quality waters
- Duk Upper Devomiam Kakisa Formation limestone. Expect maximum yields of 5 Igpm of poor to locally fair quality bicarbonate waters

 Duff Upper Devomiam Trout River and Tetcho Formations consisting mainly of limestone with minor whale and sandstone. Expect maximum yields of 5 Igpm of poor to locally fair quality generally blearbonate waters
- Upper Devonian Fort Simpson Formation marine shale and miltstone. Expect maximum yields of less than 1 Igpn of generally poor quality sulphate waters
- Middle Devonion unnamed and undivided mainly carbonate strata with minor shale and subjects. Expect maximum yields of 250 Igpm of variable quality bicarboare-sulphase vaters.

 Middle Devonion has Scarp formation reefal and other limestones. Expect maximum yields of 100 Igpm of poor to locally fair quality generally bicarbonate, hard waters
- Drmki Middle Devenian Kee Scarp Formation limestone and Hare Indian cal-careous shale. Expect maximum yields of 25 Igps of variable qual-ity generally bicarbonate, hard waters

- Middle Devonian Hume Formation limestone. Expect maximum yields of 10 Igps of variable quality generally blearbonate, hard waters Middle Devonian Camol formation shale. Expect maximum yields of 1 Igps of peer quality sulphate waters Middle Devonian Camol and Hare Indian Formations consisting mainly of shale. Expect maximum yields of 1 Igps of poor quality bicarbonate-sulphate waters

 Middle Devonian Bear Rock Formation shale. Itsmestone, and anhydrite. Expect maximum yields of 20 Igps of very poor quality generally bicarbonate-sulphate waters

 Middle Devonian Bear Rock Formation shale. Expect maximum yields of 1 Igps of poor quality suphate waters

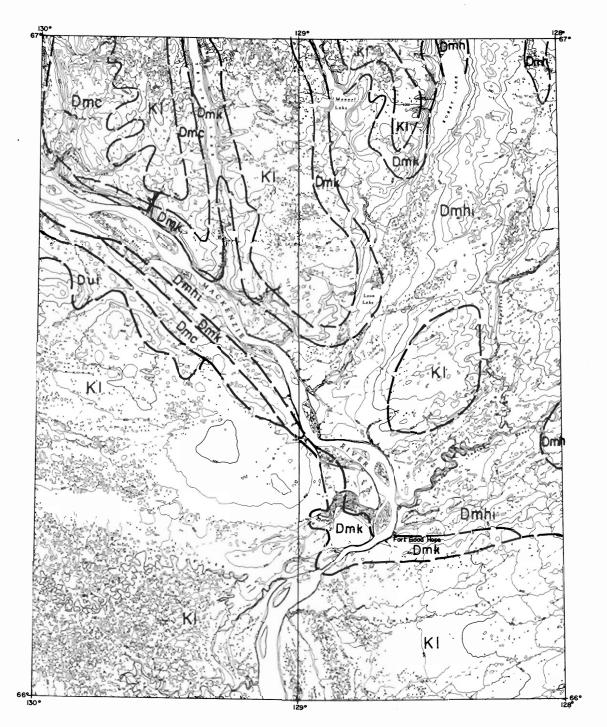
 Middle Devonian Bear shalan Formation shale. Expect maximum yields of 10 Igps of highly variable quality generally blearbonate-sulphate waters

 Ordevictan and Silurian summet and undivided dolomite and anhydrice and Franklin Mtn. Formation shales and the Expect maximum yields of 100 Igps of generally poor to locally fair quality bicarbonate-sulphate waters

 Cambrian Saline River rormation shaperite xypsum and salt, Cap Mt. Formation shale and the Clark Formation sandstone. Expect maximum yields of 100 Igps of poor quality sulphate-waters from the Cap Mt. Formation shale, and 23 Igps of fair quality waters from the Cap Mt. Formation shale, and 23 Igps of fair quality waters from the Mt. Clark Formation sandstone.
- Precambrian argillite, quartitie, and delomite. Expect maximum yields of 25 Igym of poor to fair quality waters

syncline Mop 15

Tectonic symbols: ___ thrust fault with teeth indicating direction of dip; anticlime;



FORT GOOD HOPE

RECONNAISSANCE BEDROCK HYDROGEOLOGY MAP

LECEND OF GENERALIZED BEDROCK HYDROGOLOGY MAP
SHOWING GROUND-WATER PROBABILITY ALONG MAXCHEZIE RIVER VALLEY
FORT INDEPOND TO FORT HEPHORODM, NORTHWEST TERRITORIES
(Note: The entire study-area is underlain by widespread permafront in
the disconvinuous permafront zone; also, extrastes of
yields refer to probable, not absolute, maximum figures and to generally
more highly disturbed, fractured, and porous zones within the formatums)

Symbol

Explanation

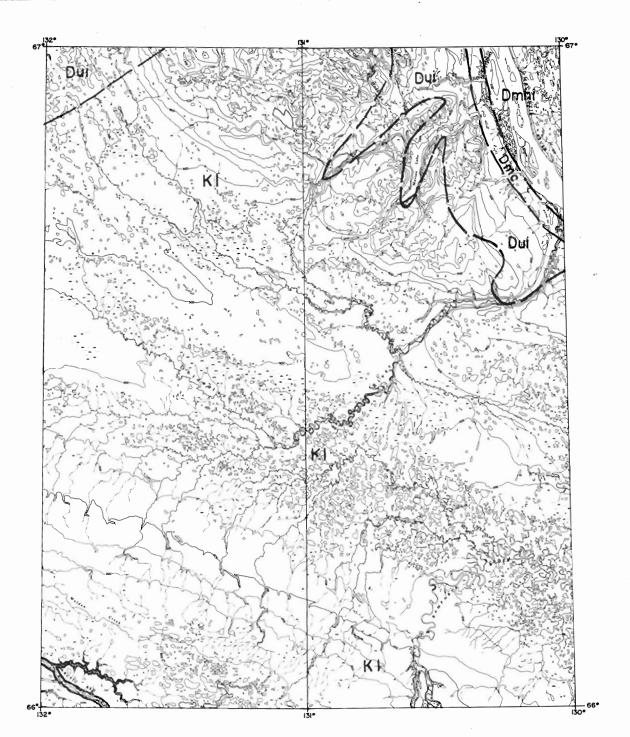
- Tertiary non-marine sand, gravel, conglowerate, shale, sandstone, coal. Expect maximum yields of 50 Igpm of generally fair to good quality waters
- Upper Cretaceous mainly non-marine sandstone and shale. Expect maximum yields of 25 Igpm of generally poor to locally fair quality
- ΚI Lower Critacous mainly marine shale and sandstone. Expect maximum yields of 1 Iggss of poor quality, sulphate waters
- Upper Crefaceous Fort St. John Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
- Upper and Lower Cretaceous unnamed and undivided mainly marine sha-le mmd sandstone. Expect maximum yields of 5 Icom of generally poor quality waters
- Carboniferous (Pennsylvanian) and Permian unnamed and undivided sand-stome and complomerate. Expect maximum yields of 25 Igpm of poor to locally fair quality waters
- Upper Devonian Redknife Formation mainly marine shale with minor namedstone and ilmestone. Expect maximum yields of 1 Igpm of generally poor quality waters

- Opper Sevenian unnamed mainly non-marine shale, siltstone, limestone, and sandatone. Expect maximum yields of 5 Igom generally poor to locally fair quality vaters
- Upper Devocion Corporation mainly non-marine shale and sand-stone. Expect maximum yields of 5 Igpm of generally poor to locally fair quality waters
- Upper Devonian Kakisa Formation limestone. Expect maximum yields of Igam of poor to locally fair quality blearbonate vaters Byper levendan Trout River and Tecch formations consisting mainly of limestone with minor shale and saedatone. Expect maximum yields of 3 ligm of poor to locally fair quality generally blearbonate exactrs
- Upper Devonian Fort Simpson Formation marine shale and siltstone.
 Expect maximum yields of less than 1 [gpm of generally poor qual-lty sullphate waters
- Middle Devonian unnamed and undivided mainly carbonate s trata with minor shale and whydrite. Expect maximum yields of 250 lgpm of variable quality bicarbonate-sulphate waters Kiddle Devonian Des Scarp Pommetian reefal and other limestones. Expect maximum yields of 100 lgpm of poor to locally fair quality generally bicarbonate, hard waters
- Drmki Middle Devonian Lee Scarp Formation limestone and Hare Indian cal-careous shale. Expect maximum yields of 25 lgpm of variable qual-ity generally bicarbomate, hard vaters

Tectonic symbols: ____ thrust fault with teeth indicating direction of dip; ____ anticline;

- Dmh Dmc

- Middle Devonian Huse Formation limestone. Expect maximum yields of 10 Igps of variable quality generally bloarbonate, hard waters Middle Devonia, Camol Mormation snale. Expect maximum yields of 1 Igps of poor quality sulphate waters in Middle Devonia, Camol and Mare Indian Formations consisting, mainly of ships. Expect maximum yields of 1 Igps of poor quality bicarbonate-walphate waters in Middle Devonian Sear Nuck Formation defeaste, limestone, and amhydrite. Expect maximum yields of 250 Igps of very poor quality generally bloarbonate-walphate waters in the property of the property
- Camérian Salise River Formation anhydrite gypsum and salt, Cap Mt. Formation shale and Mt. Clark Formation sandatome. Spect maximum yields of 100 igps of year 'quality sulphate-chloride waters from the Salien River salt and ambydrite, 1 igps of poor quality sulphate waters from the Cap Mt. Formation shale, and 25 igps of fair quality vaters from the Mt. Clark Formation sales. €cs
- Pricambelam argi llite, quartzite, and dolomite. Expect maximum yields of 25 Igp m of poor to fair quality waters
- syncline Map 16



ONTARATUE RIVER

RECONNAISSANCE BEDROCK HYDROGEOLOGY MAP

LEGEND OF GENERALIZED BEDROCK HYDROGEOLOGY MAP SHOWING GROUND-WATER PROBABILITY ALONG MACCOMPILE RIVER VALLEY FORT SIMPSON TO FORT MEPHERSON, NORTHWEST TERRITORIES

(Note: The entire study-area is underlain by widespread permafrost in the discontinuous paraelrost mose; also, estimates of yields refer to probable, not absolute, maximum figures and to generally more highly disturbed, fractured, and porous zones within the formations)

Symbol 1

- Tertiary non-marine sand, gravel, conglomerate, shale, sandstone, coal. Expect maximum yields of 50 Igpm'of generally fair to good quality waters
- Upper Cretaceous mainly non-marine sandstone and shale. Expect maximum yields of 25 Igpm of generally poor to locally fair quality
- Lower Cretaceous mainly maring whale and sandstone. Expect maximum yields of 1 Igpm of poor quality sulphate waters
- Upper Cretaceous Fort St. John Formation shale. Expect maximum yields of 1 Igps of poor quality sulphate waters
- K Upper and Lover Cretacross summanes and undivided mainly marine shale and sandatone. Expect maximum yields of 5 Igpm of generally poor quality waters

 CPG Carboniferous (Yemneylyamiam) and Permian unmaned and undivided sandatone under an employmentate. Expect maximum yields of 25 Igpm of poor to locally fair quality waters
- Upper Devenian Fedknife Formation mainly marine shale with minor sandstone and limestone. Expect maximum yields of 1 Igom of generally poor quality waters Tectonic symbols: ___ thrust fault with teeth indicating direction of dip; ___ anticline;

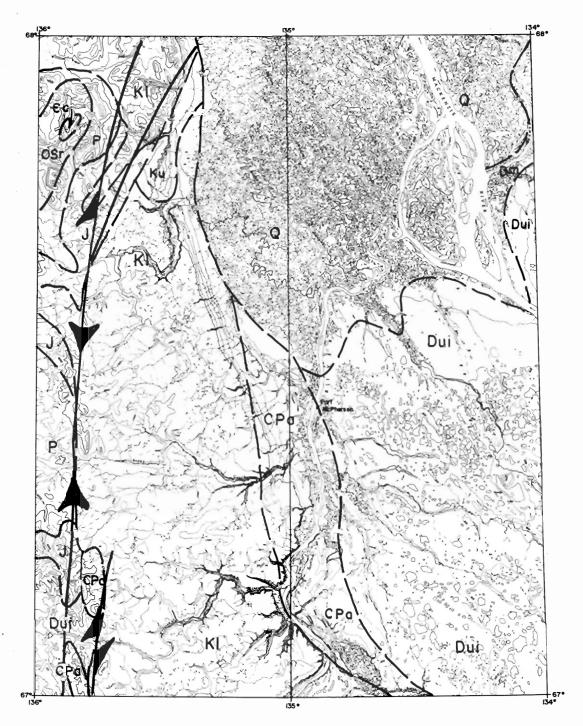
- Upper Devonian unnamed mainly non-marine shale, siltstone, limestone, and sandstone. Expect maximum yields of 5 Igpm generally poor to locally fair quality waters
- Upper Devonian Imperial Formation mainly non-marine shake and sand-stone. Expect maximum yields of 5 Igpm of generally poor to locally fair quality waters
- Upper Devonian Kakisa Formation limestone. Expect maximum yields of 5 Igom of poor to locally fair quality bicarbonate waters upper Devonian Trout River and Tetcho Formations consisting mainly of limestone with misons hable and sandatone. Expect maximum yields of 5 Igom of poor to locally fair quality processly bicarbonate waters

- Middle Devenion unmaned and undivided mainly carbonate strata with minor shale and subjective. Expect maximum yields of 250 Igpm of variable quality bicarbonate-sulphate valences
 Middle Devonion Kee Scarp Fermation reefal and other limestones.
 Expect maximum yields of 100 Igpm of poor to locally fair quality generally bicarbonate, hard waters
- Drmki Middle Devomiam Kee Scarp Formation limestone and Hare Indian cal-careous shale. Expect maximum yields of 25 Igpm of variable qual-ity generally bicarbonate, hard waters

- Middle Devonian Hume Formation limestone. Expect maximum yields of 10 Igpm of variable quality generally bicarbonate, hard waters Middle Devonian Canol Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters Middle Devonian Canol and Hare Indian Formations consisting mainly of shale. Expect maximum yields of 1 Igpm of poor quality bicarbonate-sulphate waters Middle Devonian Bear Pook Formation delente. Limestone and applydential control of the property of the prope

- conace-sulphate waters
 Middle Devonian Bear Rock Formatism dolomite, limentone, and amhydrite. Expect maximum yields of 200 Igpm of very poor quality bleathmiddle Devonian Bear Rock Formatism dolomite, limentone, and amhydrite. Expect maximum yields of 200 Igpm of very poor quality generally becarbonate-sulphate waters
 Middle Devonian Hare Todism Formation shale. Expect maximum yields
 of 1 Igpm of poor quality sulphate vaters
 Ordovician and Silvian wasmand and undivided dolomite and limestone. Expect maximum yields of 10 Igpm of highly warrable quality
 generally bicarbonate-sulphate vaters
 Ordovician and Silvian Womant Kindle Formation delomite and anhydrite and Franklin Mtm. Formation dolomite and shale. Expect maximum
 yields of 100 Igpm of generally poor to locally fair quality bicarbonate-sulphate waters
- onate-supphase waters
 Cambrian Saline River Formation anhydrite gypsum and salt, Cap Mt.
 Formation shale and Mt. Clark Formation sandatome, Expect maximum
 yields of 100 Igpm of poor quality sulphate-chleride waters from th
 Saline River salt and anhydrite, 1 Igpm of poor quality sulphate waters from the Cap Mt. Formation shale, and 25 Igpm of fair quality
 waters from the Mt. Clark Formation sandatoms
- Precambrian argillite, quartzite, and dolomite. Expect maximum yields of 25 Igpm of poor to fair quality waters

Map 17 - syncline



FORT McPHERSON

RECONNAISSANCE BEDROCK HYDROGEOLOGY MAP

LEGEND OF GENERALIZED BEDROCK HYDROGEOLOGY MAP SHOWING GROUND-WATER PUBBABILITY ALONG MACKENZIE RIVER VALLEY FORT SIMPSON TO FORT MCPHERSON, NORTHWEST TERRITORIES

(Note: The entire study-arms is underlain by widespread permafrost in the discontinuous permafrost zone; elso, estimates of yields refer to probable, not absolute, maximum figures and to generally more highly disturbed, fractured, and porous zones within the formations)

Symbol |

- Explanation Tertiary non-marine aand, gravel, conglomerate, shale, sandstone, coal. Expect maximum yields of 50 Igpm of generally fair to good quality waters
- Κu Upper Cretaceous mainly non-marine sandstone and shale. Expect maximum yields of 25 Igpm of generally poor to locally fair quality waters
- Lower Cretaceous mainly marine shale and sandstone. Expect maximum yields of 1 Igom of poor quality sulphate waters
- Upper Cretaceous Fort St. John Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
- Upper and Lower Cretaceous unnamed and undivided mainly marine shale and sandstone. Expect maximum yields of 5 Igpm of generally poor quality waters

 Carboniferous (Pennsylvenian) and Permian unnamed and undivided sandstone and complemerate. Expect maximum yields of 25 Igpm of poor to locally fair quality waters
- CPa
- Upper Devoniam RedRnife Formation mainly marine shale with minor sandstone and limestone. Expect maximum yields of 1 Igpm of generally poor quality waters

- Upper Devonian unnamed mainly non-marine shale, siltstone, linestone, and sandstone. Expect maximum yields of 5 Igpm generally poor to locally fair quality waters
- Upper Devonian Imperial Formation mainly non-marine shale and sand-stone. Expect maximum yields of 5 Igpm of generally poor to locally fair quality waters
- Upper Devonian Kakina Formation limestoom. Expect maximum yields of 5 Igpm of poor to locally fair quality blearbonate waters
 Upper Devonian Trout River and Tetcho Tormations consisting mainly
 of limestone with misor shale and sandstone. Expect maximum yields
 of 5 Igpm of poor to locally fair quality generally bicarbonate
 waters
- Upper Devonian Fort Simpson Formation marine shale and siltstone. Expect maximum yields of less than 1 Igpm of generally poor quality sulphate waters
- Middle Devonian unnamed and undivided melaly carbonate strata with minor shale and anhydrite. Expect maximum yields of 250 Igpm of variable quality bicarbonate-sulphate vaters
 Middle Devonian Kee Scarp Formation reefal and other limestones.
 Expect maximum yields of 100 Igpm of poor to locally fair quality generally bicarbonate, hard waters
- Drmki Middle Devonian Kem Scarp Formation limestone and Hare Indian cal-careous shale. Expect maximum yields of 25 Igpm of variable qual-ity generally bicarbonate, hard waters

- Middle Devonian Hums! Formation limestone. Expect maximum yields of 10 Igpm of variable quality generally bicarbonste, hard waters Middle Devonian Canol Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters Middle Devonian Canol and Hare Indian Formations consisting mainly of shale. Expect maximum yields of 1 Igpm of poor quality bicarbonate-sulphate waters.
- Middle Devonian Bear Rock Formation dolomite, limestone, and anhyd-rite. Expect maximum yields of 250 Igpm of very poor quality gene-rally bicarbonate-sulphate waters
- Middle Devonian Mare Indian Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
- oi I ign or poor quality suphate waters of condition and limestone. Expect maximum yields of 10 Igns of highly variable quality
 generally bitcathonate-sulphate waters
 Ordovicism and Silurian Hount Kindle Formation, dolomite and anhydrite and Franklin Htm. Formation dolomite and whale. Expect maximum
 yields of 100 Igns of generally poor to locally fair quality bicathonate-sulphate waters
- onate-sulphate waters

 Cambrian Sallow Kiver Yermation anhydrite gypsum and salt, Cap Mt.

 Formation shale and Mt. Clark Formation sandstone. Expect maximum

 yields of 100 Igpm of poor quality sulphate-chloride waters from the

 Saline River salt and sanbydrite. 1 Igpm of poor quality sulphate wa
 ters from the Cap Mt. Formation shale, and 25 Igpm of fair quality

 waters from the Mt. Clark Formation sandstone
- Precambrian argillite, quartzite, and dolomite. Expect maximum yields of 25 Igpm of poor to fair quality waters

Tectonic symbols: ____ thrust fault with teeth indicating direction of dip; ____ anticline;



ARCTIC RED RIVER

RECONNAISSANCE BEDROCK HYDROGEOLOGY MAP

LEGEND OF GENERALIZED BEDROCK HYDROGEOLOGY MAP SHOWING GROUND-WATER PROBABILITY ALONG MACKENZIE RIVER VALLEY FORT SIMPSON TO FORT MCPHERSON, NORTHWEST TERRITORIES

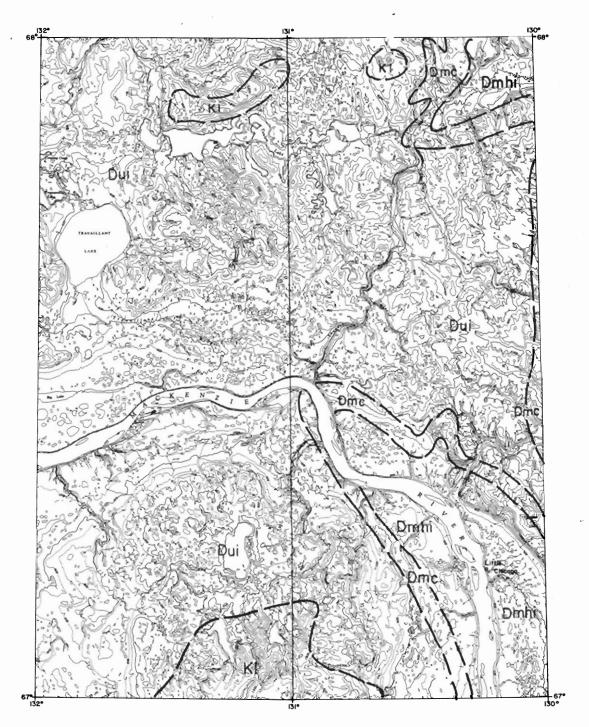
(Note: The entire study-area is underlain by widespread permafrost in the discontinuous permafrost zone; also, exthences of yields refer to probable, not absolute, maximum figures and to generally more highly disturbed, fractured, and porous zones withis the formations)

- Tertiary non-marine sand, gravel, conglomerate, shale, sandstone, coal. Expect maximum yields of 50 Igpm of generally fair to good quality waters
- Upper Cretaceous mainly non-marine sandstone and shale. Expect maximum yields of 25 Igpm of generally poor to locally fair quality waters
- Lower Cretaceous mainly marine shale and sandstone. Expect maximum yields of 1 Igpm of poor quality sulphate waters
- Upper Cretaceous Fort St. John Formation shale. Expect maximum yields of 1 Isom of poor quality sulphate waters
- Upper and Lower Cretaceous unnamed and undivided mainly marine shale and sandstone. Expect maximum yields of 5 Igpm of generally poor quality waters
- Carboniferous (Pennsylvanian) and Permian unnamed and undivided sand-stone and conglowerate. Expect maximum yields of 25 Igpm of poor to locally fair quality waters
- Upper Devonian Madkmife Formation mainly marine shale with minor sandstone and limestme. Expect maximum yields of 1 Igpm of generally poor quality waters

- Upper Devonian innamed mainly non-marina shale, siltstone, limestone, and sandstone. Expect maximum yields of 5 Igpm generally poor to locally fair quality waters
- Upper Devomiam Imperial Formation mainly non-marine shale and sand-stone. Expect maximum yields of 5 Igpm of generally poor to locally fair quality waters
- Upper Devonian Kakisa Formation limestone. Expect maximum yields of 5 Igpm of poor to locally fair quality bicarbonate waters
 Upper Devonian Trout River and Tetcho Formations consisting mainly of limestone with minor while and sandstone. Expect maximum yields of 5 Igps of poor to locally fair quality generally bicarbonate
- Upper Devomian Fort Simpson Formation marine shale and siltstone. Expect maximum yields of less than 1 Igpm of generally poor quality sulphate waters
- Middle Devonian unnamed and undivided mainly carbonate atrata with minor shale and anhydrice. Expect maximum yields of 250 Igpm of variable quality bicarbonate-sulphate waters
- Hiddle Evonian Kee Scarp Formation reefal and other limestones. Expect maximum yields of 100 Igym of poor to locally fair quality generally bicarbonate, hard waters
- Drmki Middle Devonian Kee Scarp Formation limestone and Hare Indian cal-careous shale. Expect maximum yields of 25 Igpm of variable qual-ity generally bicarbonate, hard water. Tectonic symbols: ____ thrust fault with teeth indicating direction of dip; ____ anticline;

- Middle Devonian Hume Formation limestone. Expect maximum yields of 10 Igpm of variable quality permetally bicarbolate, hard watern
- Middle Devonian Canol Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters

- Igps of poor quality sulphate vaters which be wished beyond: Canol and Mare Indian Formations consisting Mainly of shale. Expect maximum yields of 1 Igps of poor quality bicarbonate-aulphate vaters with the poor quality bicarbonate-aulphate vaters. Hiddle Devonian Bear Rock Formation dolomite, limestone, and shydrite. Expect maximum yields of 250 Igps of very poor quality generally bicarbonate-aulphate vaters. Hiddle Devonian Hare Indian Formation shale. Expect maximum yields of 1 Igps of poor quality sulphate vaters. Ordovician and Silvatam unnamed and undivided dolomite and limestone. Expect maximum yields of 10 Igps of most of highly variable quality generally bicarbonate-sulphate vaters. Ordovician and Silvatam Mount Kindly Formation dolomite and anhydrite and Franklin Mun. Fyrmation dolomite and shale. Expect maximum yields of 10 Igps of mereally poor to locally fair quality bicarbonate-sulphate vaters.
- onate-sulphaty valeurs
 Cambrian Salie Biwer Pyrmation anhydrite gypoon and salt, Cap Mt.
 Formation shale and Mt. Clark Formation sandatome. Expect maximum
 yields of 100 Iggs of por quality sulphate-obletide vaters from the
 Saline River salt and schydrive, 'Saw of poof quality sulphate vaters from the Cap Mt. Formation shale, and 23 Igm of fair quality
 waters from the Mt. Clark Formation sendstone
- Precambrian argillite, quartzite, and dolomite. Expect maximum yields of 25 Igpm of poor to fair quality waters



TRAVAILLANT LAKE

RECONNAISSANCE BEDROCK HYDROGEOLOGY MAP

LEGEND OF GENERALIZED BEDROCK HYDROGEOLOGY MAP SHOWING GROUND-MATER PROBABILITY ALONG PLACEDZIE RIVER VALLEY FORT SIMPSON TO FORT MAPHERSON, NORTHWEST TERRITORIES

(Note: The entire study-area is underlain by widespread permatrost in the distrontineous permatrest rons; also, extinates of yields refer to probable, not absolute, maximum figures and to generally more highly disturbed, fractured, and porous zones within the formatisms)

Symbol

Explanation

- Tertiary non-marine sand, gravel, conglowerate, shale, sandstone, coal. Expect maximum yields of 50 Igpm of generally fair to good quality waters
- Upper Cretaceous mainly non-marine sandstone and shale. Expect maximum yields of 25 Igpm of generally poor to locally fair quality waters
- Lower Cretaceous mainly marine shale and sandstone. Expect maximum yields of 1 Igpm of poor quality sulphate waters
- Upper Cretaceous Fort St. John Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
- Upper and Lower Cretaceous unnamed and undivided mainly marine shale and sandstone. Expect maximum yields of 5 Igpm of generally
- ne mm sandstone. Expect maximum yields of 7 kgpm of generally poor quality waters Carboniferous (Pennsylvaniam) and Permian unnamed and undivided sand-stone and conglomerate. Expect maximum yields of 25 Igpm of poor to locally fair quality waters CPa
- Upper Invonion Redenife Formation mainly marine shale with minor sandstone and limestone. Expest maximum yields of 1 Igpm of generally poor quality waters

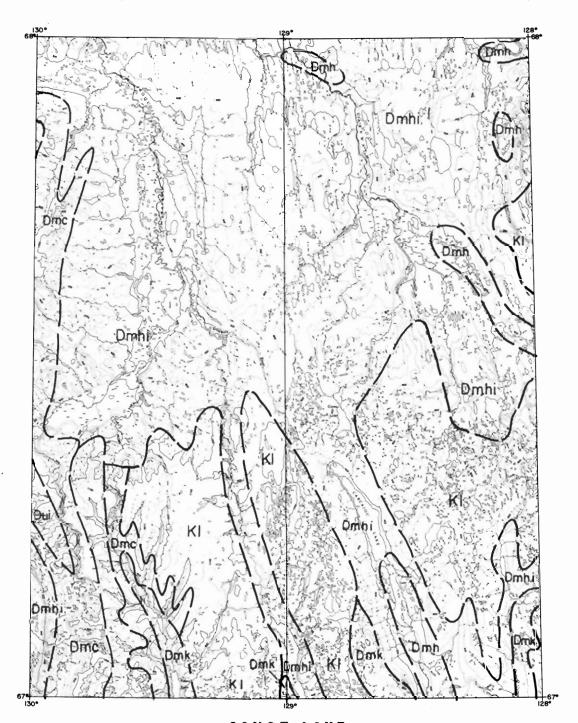
- Upper Devonian unnamed mainly non-marine shale, siltatone, limestone, and sandatome. Expect maximum yields of 5 Igpm generally poor to locally fair quality waters
- Upper Devonian Imperial Formation mainly non-marine shale and sand-stone. Expect maximum yields of 5 Igpm of generally poor to locally fair quality waters
- Duk Upper Devonian Kakiaa Formation limestone. Expect maximum yields of 5 Igpm of poor to locally fair quality bicarbonate waters

 Dut! Upper Devonian Troug Kiwer and Techo Formations consisting mainly of 15 mercome with minor shale and sandstone. Expect maximum yields of 5 Igpm of poor to locally fair quality generally bicarbonate waters
- Upper Devonian Fort Simpson Formation marine shale and siltstone. Expect maximum yields of less than 1 Igpm of generally poor quality sulphate waters
- Middle Devonian unnamed and undivided mainly carbonate strata with minor shale and anhydrite. Expect maximum yields of 250 Igom of variable quality bicarbonate-sulphase raters
 Middle Devoniam Kee Scrip Forman iom revial and other limestones.
 Expect maxim my yields of 100 Igom of poor to locally fair quality generally bicarbonate, hard waters
- Drmki Middle Devonian Kee Scarp Formation likestone and Hare Indian cal-careous shale. Expect maximum yields if 25 Igpm of variable qual-ity generally bicarbonate, hard Manager
- syncline Tectonic symbols: ____ thrust fault with teeth indicating direction of dip; ____ anticline;

- os
- Middle Devonian Hume Formation limestone. Expect maximum yields of 10 Igpm of variable quality generally bicarbonate, hard waters Middle Devonian Canol Formation shale. Expect maximum yields of 1 Igpm of poor quality subplate waters littles Devonian Canol and Hare Indian Formations consisting mainly of shale. Expect maximum yields of 1 Igpm of poor quality yields and important of the property of
- onate-sulphate waters

 Cumbrims laine River Formation anhydrite gypsum and salt, Cap Mt.

 Formation shale and Mt. Clark Formation sandstone. Expect maximum yields of 100 Igpm of poor quality wulphate-chloride waters from the Saline River salt and ambydrite, I Igpm of poor quality sulphate waters from the Cap Mt. Formation shale, and 25 Igpm of fair quality waters from the Mt. Clark Symmaton shale, and 25 Igpm of fair quality waters from the Mt. Clark Symmaton smales one
- Precambrian argillite, quartzite, and delomite. Expect maximus yields of 25 Igpm of poor to fair quality waters



CANOT LAKE RECONNAISSANCE BEDROCK HYDROGEOLOGY MAP

LEGEND OF GENERALIZED BEDROOK MYDROCCOLOGY MAP
SHOWING GROUND-VACUE PROBABILITY ALONG MACCOUNTE RIVER VALLEY
FORT SIMPSON TO FORT MCPHERSON, NORTHWEST TERRITORIES

(Note: The entire study-area is underlain by widespread permifront in the discontinuous permafront zone; also, estimates of yields refer to probable, not absolute, maximum figures and to generally more highly disturbed, fractured, and persus rooms within the formations)

Symbol

Explanation

- Tertiary non-marine sand, gravel, conglowerate, shale, sandstone, coal. Expect maximum yields of 50 Igpm of generally fair to good quality waters
- Upper Cretaceous mainly non-marine sandstone and shale. Expect maximum yields of 25 Igps of generally poor to locally fair quality waters
- Lower Cretaceous mainly marine shale and sendstone. Expect maxin-um yields of 1 Igpm of poor quality aulphats waters
- Opper Creinceous Fort St. John Formation shale. Expect maximum yields of 1 Igpm of poor quality sulphate waters
- Upper and Lower Creticeous unnamed and undivided mainly marine shale and sandstone. Expect maximum yields of 5 Igpm of generally
- le and sandstone. Expect maximum yields of 5 Igpm of generally poor quality waters

 Carboniferous (Pennaylvanian) and Fermian wenamed and undivided sandstone and congourate. Expect maximum yields of 25 Igpm of poor to locally fair quality-waters.
- Upper Devenian Redunit's Formation mainly marine shale with minor sandstone and limestone. Expect maximum yields of 1 Igpm of generally noor quality waters

- Upper Devonian unnamed mainly non-marine shale, silvetone, limetone, and sandstone. Expect baximum yields of 5 Igpm generally meer to locally fair quality waters
- Upper Devonian Imperial Formation mainly non-marine shale and $s_{\rm min}/s_{\rm min}$ stone. Expect maximum yields of 5 Igpm of generally poor to $1_{\rm Gal} | 1y$ fair quality waters Dui
- Duk Upper Devonian Kaisa Parmation limestone. Expect maximum yields of 5 Igps of poor to locally fair quality bicarbonate waters

 Dut! Upper Devonian Frank fiver and Tetche formations consisting mainly of limestone with misser shale and sandgene. Expect maximum yields of 5 Igps of poor to locally fair quality generally bicarbonate waters
- Upper Devonian For Simpson remarks marine smale and militatione. Expect maximum yields of less than 1 Igps of generally poor quality sulplate waters,
- Middle <u>Nevonian</u> unuased and undivided mainly carbonate etrata with minor shale (and anlydrite. Expect maximum yields of 250 Iggm of Variable quality hicarbonate-sulphate vaters
- Middle Devonian Res Scarp Formation reefal and other linestones. Espect maximum yields of 100 igms of poor to locally fair quality generally bicarbosate, hard waters
- Drmi Middle Devonian Kee Scarp Formation Limestone and Hare Indian calcareous shale. Expect maximum yields of 25 Igpu of variable quality generally bicarbonae, hard waters Tectonic symbols: Athrust fault with teeth indicating direction of dip: | metic line;

- Middle Devonian Hume Formation linestone. Expect maximum yizimin of 10 Igpm of variable quality generally bicarbonate, hard vating Middle Devonian Camol Formation shale. Expect maximum yielin out? I Igpm of non requirity subplate vaters Middle Devonian Camol and Hare Indian Formations commissing mainly of main. Expect maximum yields of 1 Igpm of poor quality hicarbonate-sulphate vaters? Middle Devonian Hare Indian Formation dolomite, literatome, and anhydrite. Expect maximum yields of 250 Igpm of very poor quality generally licarbonate-sulphaty vaters Middle Devonian Hare Indian Formation shale. Expect maximum yields of 1 Igpm of poor quality sumphate vaters Ordovician and Silurian vamemed and undivided dolomite and linest-one. Expect maximum yields of 10 Igpm of highly variable quality generality out and Franklin Min. Jornation delomite and shale. Expect maximum yields of 100 Igpm of generally poor to locally fat quality bloarbonate-sulphate vaters onate-sulphate waters

 Cambrian Saline River Formation anhydrike gypnums and sali, Cap Mt.

 Formation shale and Mt. Clark Formation sandatone. Expect maximum

 xicids of 100 Jgnn of poor quality sulphate-chloride waters from th

 Saline Hiver sali and subsylrike, I Ignn of poor quality sulphate waters from the Cap Mt. formation shale, and 23 liph of fair quality

 waters from the Mt. Clark 100 and and dead of the control of t
- Precambrian argillite, quantizate, and delemite. Expect maximum yields of 25 Igom of poor to fair quality watered

